THE TWENTY-SIXTH KELVIN LECTURE

"THE MOLECULAR STRUCTURE OF DIELECTRICS."

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(*Lecture delivered before* THE INSTITUTION *2nd May*, 1935.)

The dielectric properties of a substance must be closely related to the nature and spatial relations of the atoms and molecules of which it is composed. During the last quarter of a century our knowledge of the structure of solid bodies has been greatly increased by the discovery and development of the methods of X-ray analysis. On this occasion of the Silver Jubilee it is of no little interest to observe that the period is exactly that of the King's reign. We begin to have accurate information of the distances that separate the atoms within the molecule and of the mutual orientations which they tend to assume. We begin to understand also the ways in which molecules fit themselves together so as to form the solid. The X-ray methods are at their best when they have to deal with the bodies which we call crystals, wherein the atoms and molecules are arranged in perfect order, following some pattern which repeats itself in all directions in the space within the bounds of the crystal. At one time this seemed to foreshadow a severe limitation to the usefulness of the methods. The apprehension has fortunately proved to be entirely mistaken for we find that the orderly arrangement, which is carried out to the full in the perfect crystal, is extremely common in less degree within bodies which show no outward trace of it, such as resins and rubber and wool. There are very few bodies in which there is not some degree of order. So long as this is the case the X-ray analysis finds opportunity for employment.

Liquids lend themselves to X-ray investigation far less readily than solids, but the direct applications are helpful nevertheless. Moreover, it is found that the molecule possesses a measure of rigidity and constancy of form which justifies the assumption that its structure is often very much the same in the liquid as in the solid, and that even when a serious change of structure does occur many of the spatial relations remain unchanged.

In this lecture I propose to give in the first place a brief account of those features of the solid body on which the X-rays throw an especial light, such as the quantitative measurements of the atomic distances and mutual orientations to which I have referred. I hope, and indeed believe, that the information supplied by the X-ray methods can be of some use to those who are trying to solve the extremely complicated problems of the dielectric phenomena. I might stop at that point and leave any discussion of such information to the technical expert; but I propose to go a little farther, and to suggest its possible uses. I know well, of course, that in doing so I am venturing upon ground with which my acquaintance is comparatively small. The work done upon this extremely important question has produced an extensive literature which presents an appalling aspect to the outsider. I have tried to grasp some of the essential points. For any success in my attempt I have to thank Dr. Whitehead and others who have tried to make me see where the essentials are to be found. My reason for venturing on this overlapping is simply this, that if we are to derive any benefit from the comparison of a problem of pure research with a highly technical development, it is well to interleave our separate branches of knowledge as much as possible.

One of the most informative methods of presenting the results of X-ray analysis is that which depends on the construction of what may be called an "electron map." Such a map is given in Figs. 1 and 2. The molecule here described is that of "durene," an organic molecule consisting of a benzene ring in which four of the hydrogens have been replaced by methyl groups, as shown in the ordinary chemical diagram alongside (Fig. 1), with which the map is to be compared. The contour lines indicate the various degrees of electron density within the molecule, projected upon the so-called *ac* plane (see the legends attached to the figures). The atoms are easily distinguishable except that the hydrogens always melt into the carbon atoms to which they are attached. The unit of pattern of durene is contained within a prismatic cell, the height of the prism being 5·77 Ångström units (1 Å $= 10^{-8}$ cm), and the transverse section a parallelogram of which the sides are 11·57 Å and 7·03 Å and the angle 113·3°. The unit consists of two molecules, of which one only is shown. The projection is made upon the transverse section; each atom appearing as an electron cloud. The positive nuclei do not appear because they have no appreciable action on the X-rays, and the map is put together from observations of X-ray effects, in a manner which I will explain presently. The molecule is not quite normal to the direction of projection. In making these maps it is necessary for practical reasons to project in a direction parallel to a side of the cell, or at least in some other important direction. The molecule in this case, as in very many others, does not lie normally to the axis of the prism.

When allowance has been made for the obliquity by observation of other projections, it is found that the hexagon is actually regular, the length of each side being 1·41 Å, and that all the carbon atoms lie on one plane. The observations are of sufficient accuracy to permit of such statements of length and angle with a probable error of about 1 per cent.

Electron maps have been made of several other important organic molecules. I have chosen durene as a first example because the molecule stands out so well

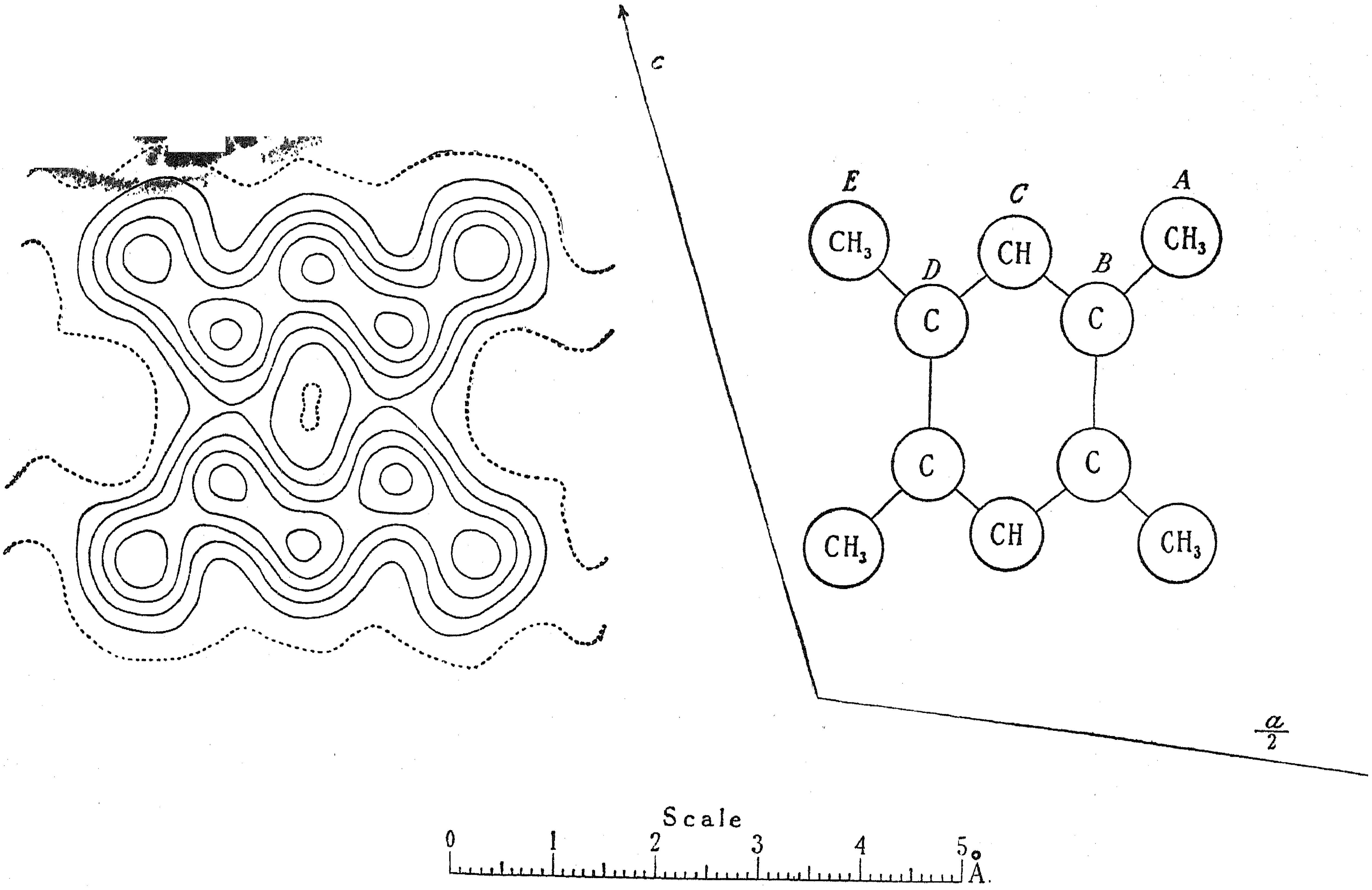


Fig. 1.—On the left is the electron map of a molecule of durene. The electron density is projected upon the *ac* plane of the cell which contains the unit of pattern. The contour lines are graded by steps of 1 electron per Ångström unit of area, i.e. per 10^{-16} cm^2. The accuracy in the denser parts of the figure is about that represented by the width of a contour line. On the right is the diagrammatic arrangement deduced from the electron map. $a = 11{\cdot}57$; $b = 5{\cdot}77$; $c = 7{\cdot}03$; *b* is perpendicular to *ac*; the angle between *a* and *c* is 113·3°. [J. M. Robertson, *Proceedings of the Royal Society*, A, 1933, vol. 142, p. 666.]

from its neighbours: sometimes there is much overlapping and the projection is then more confused. This durene map has been constructed by Dr. J. M. Robertson. As a second example I will take the molecule of cyanuric triazide (Figs. 3 and 4), a substance of great interest because of its remarkable constitution, 12 out of its 15 atoms being nitrogens. It is highly explosive. The cell contains two molecules, and has the same prismatic form as durene, the dimensions being, of course, different. This map is due to Miss Knaggs.

By means of investigations like these it is possible to determine with great accuracy the spatial relations of atoms and molecules. The calculations are heavy, but the results seem to be sufficient recompense for the work that they involve. Only a few crystals have been subjected to this special form of examination, but a great number have been analysed by means less troublesome though not quite so accurate. It is not to be forgotten also that there are other methods than those based on the use of X-rays, such as that of electron diffraction, and methods depending on the determination of dipole moments, or moments of inertia, or on the use of molecular beams. The X-ray methods differ from most of these in that they reveal the arrangement in the interior of the solid body, where the molecules are linked up with

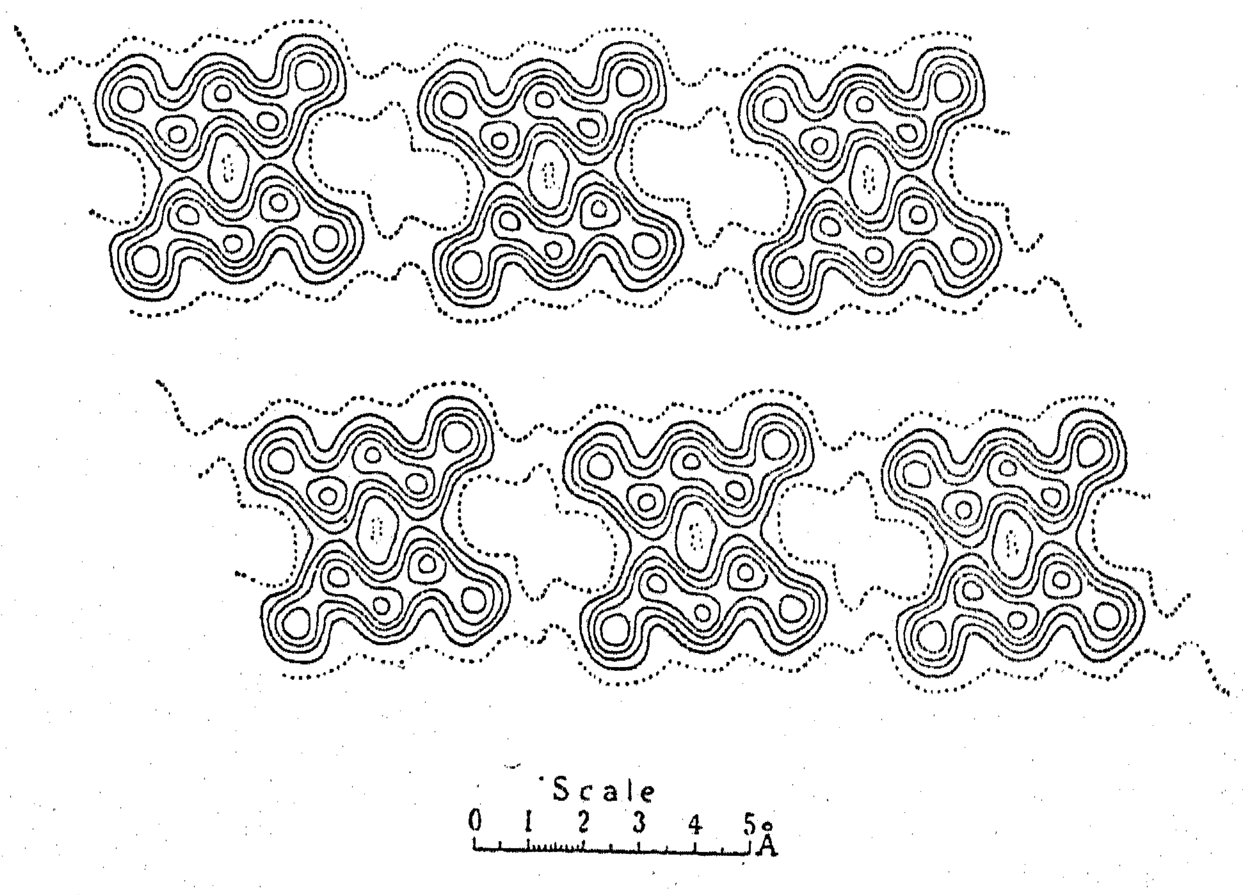


Fig. 2.—A series of durene molecules projected on the *ac* plane. This shows the relative spacings of the molecules in the crystal. [J. M. Robertson, *Proceedings of the Royal Society*, A, 1933, vol. 142, p. 667.]

their neighbours and so give the solid the characteristics peculiar to it. The constancy of form of the molecule, to which I have already referred, permits useful comparisons of the results obtained by all methods.

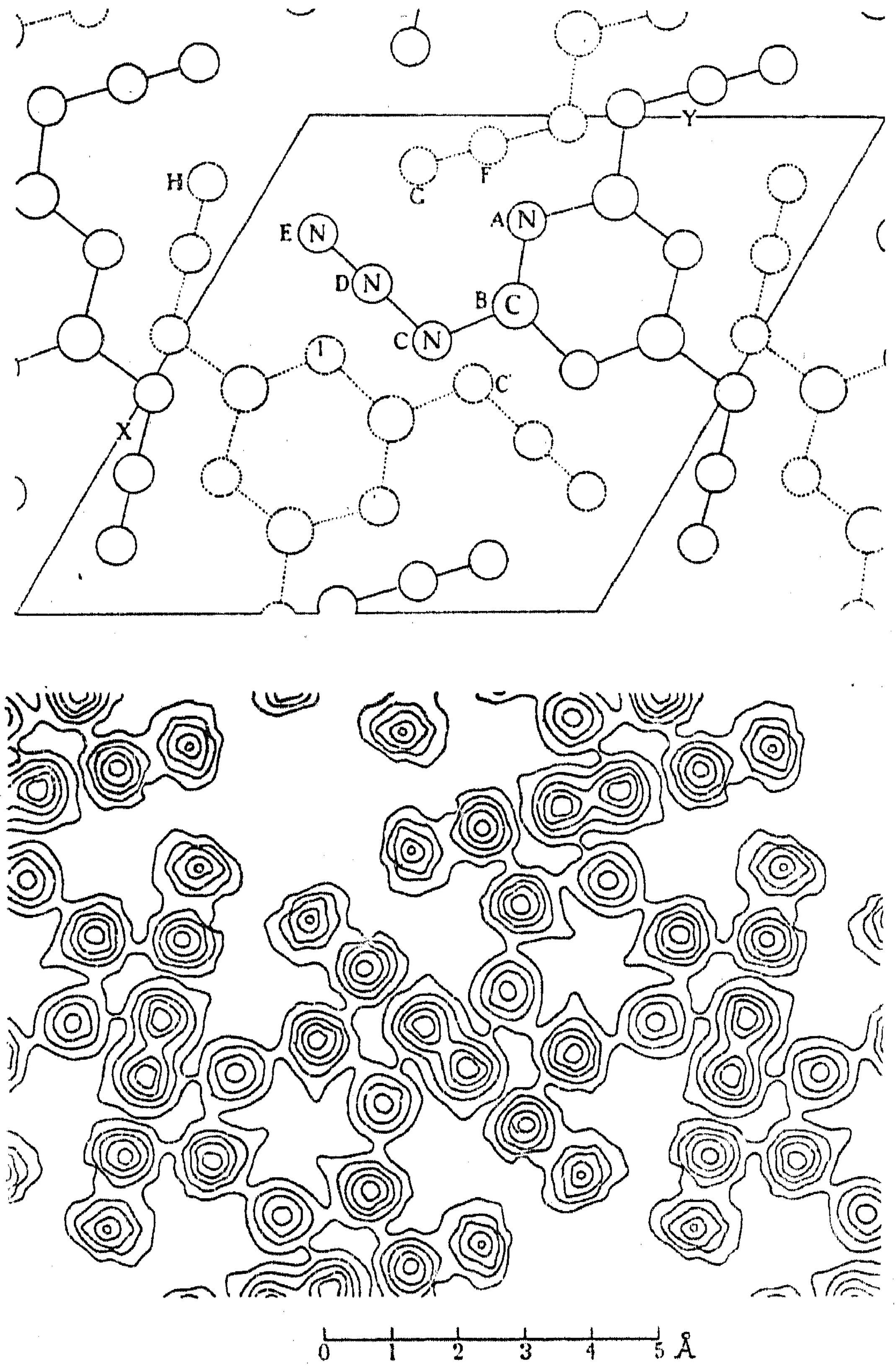


FIG. 3.—Cyanuric triazide C_3N_{12}. The upper figure shows diagrammatically the form and arrangement of the molecules in the crystal: the molecules represented by dotted lines lie behind those represented by plain lines. The carbon atoms are represented by larger circles. The lower figure is the electron map from which the upper figure is deduced. [Miss KNAGGS.]

All the results so far obtained show the benzene ring to be uniformly a regular hexagon, lying in a plane, the length of each side being 1·41 Å. It is surely a matter of great importance to realize that in whatever structure the benzene ring occurs, it possesses the same form and dimensions. We have to think of it as a strong framework, unyielding in form and dimensions, no matter of what structure it is a part. It is naturally of great assistance in forecasting structures as yet not analysed if we may depend on a rigid obedience to simple rules.

The single, double, and treble bonds of the chemist are found to correspond to differences in atomic distances. Thus the single bond which in diamond governs the whole structure corresponds to a distance of 1·54 Å between each pair of carbon neighbours. The same bond and the same distance are found in the saturated chains of the paraffins, fatty acids, alcohols, and the like. When, however, the bond between two carbon atoms is double as in benzoquinone (Fig. 5), the structure of which has just been worked out by Dr. Robertson, the distance is reduced to 1·30 Å. The hexagonal ring of six carbon atoms is not regular in this case, because three of its sides represent permanent double bonds, and the other three represent single. The lengths are 1·52 Å and 1·30 Å alternately. It is very interesting to observe that in benzene there is—according to chemical views—some sort of continuous alternation in the bonds, so that each side is in a way an average between double and single; and correspondingly the 1·41 Å of benzene is the average between the 1·52 Å and 1·30 Å of the two forms of bond.

Again, in cyanuric triazide the distance between the centres of two nitrogen atoms bound by a double bond is 1·26 Å, while the treble bond at the end of the azide group corresponds to a length of only 1·11 Å. According to Vegard's work the distance between the centres of N_2 is only 1·065 Å: assuming all experiments to be sufficiently accurate, this implies that the junction of the two nitrogen atoms of the molecule is even stronger than that of the treble bond, a result which seems to be supported by a comparison of the heats of combination.

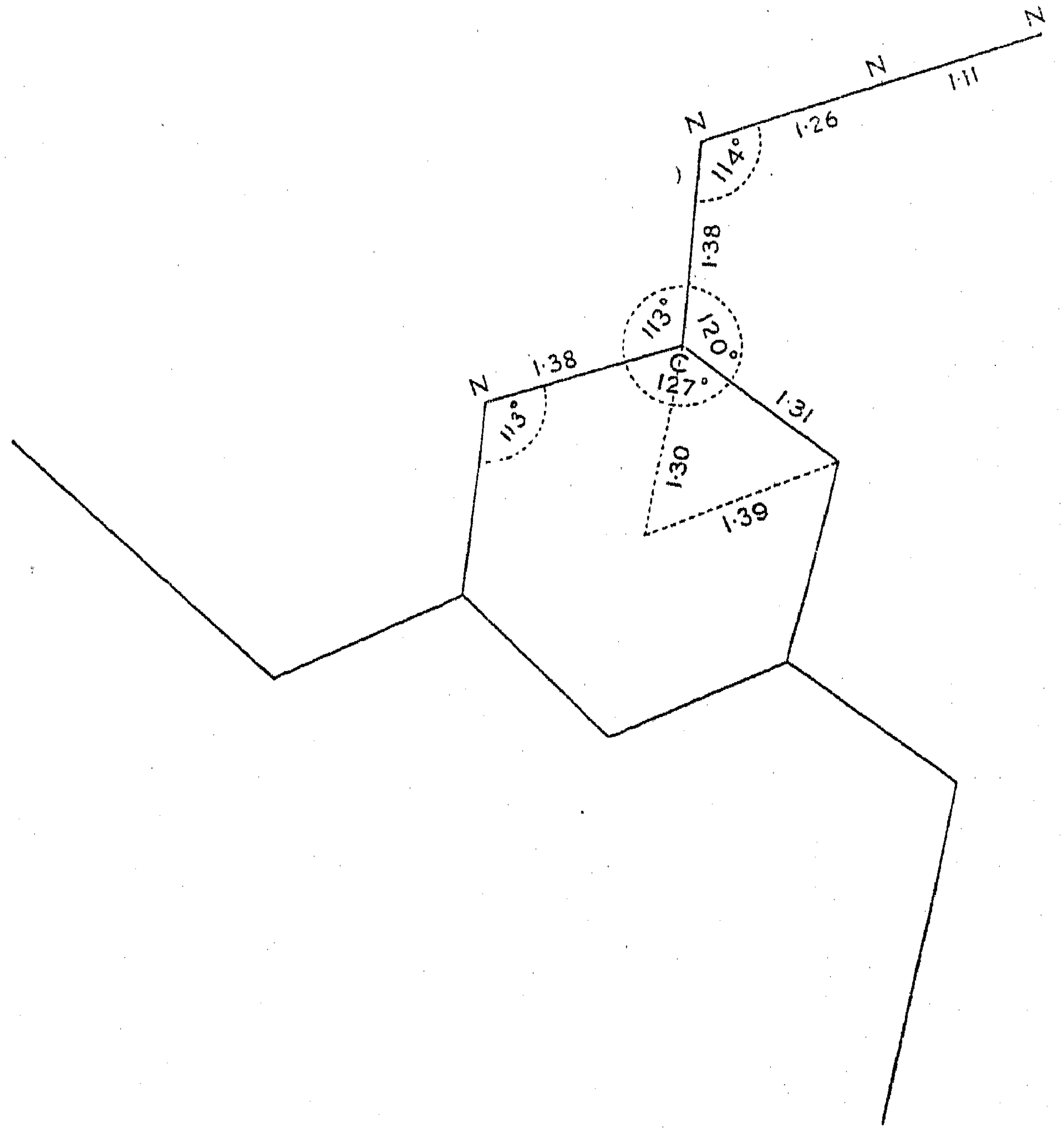


FIG. 4.—Cyanuric-triazide molecule, showing distances and angles as deduced from electron map of Fig. 3. [Miss KNAGGS.]

I have chosen these illustrations of electron projection from the organic field, because the substances used as dielectrics are so largely of organic origin. The organic molecules are in a great number of cases clearly defined and separate. Their distances from one another in the solid, i.e. the distances of closest approach of atoms belonging to one molecule to atoms belonging to another molecule, are generally 2–3 times the distances between atom and atom in the one molecule. When an organic substance melts or sublimes, the molecules part company, but not the atoms in the molecule.

When the molecules lie side by side in the crystal they do not dispose themselves so conformably as might be expected. The arrangement of the molecules in durene (Fig. 2) shows a certain tilt in each, relative to the rank in which it lies. No reason has yet been given for this, but it seems to imply a certain stiffness and a refusal to be bent so as to make a better fit. In the single molecule of durene there is a certain bending—of about 3°—of the line joining the centre of the methyl radicle to its related carbon in the ring, a bending which puts the bond out of line with the diameter of the hexagon. It may be described as due to "steric hindrance" or to a mutual repulsion of the methyl groups. The general inference is, however, that such bendings and deformations offer considerable resistance, so that, for example, the benzene ring keeps its flatness, though it does not lie parallel to its neighbours, and indeed it has little symmetry in its position relative to them. It is important to observe that there is nothing to contradict the chemical inference that rotation round a single bond is possible: or that rotation about a double bond is not. As results accumulate it would seem that both these deductions from chemical observations will be confirmed.

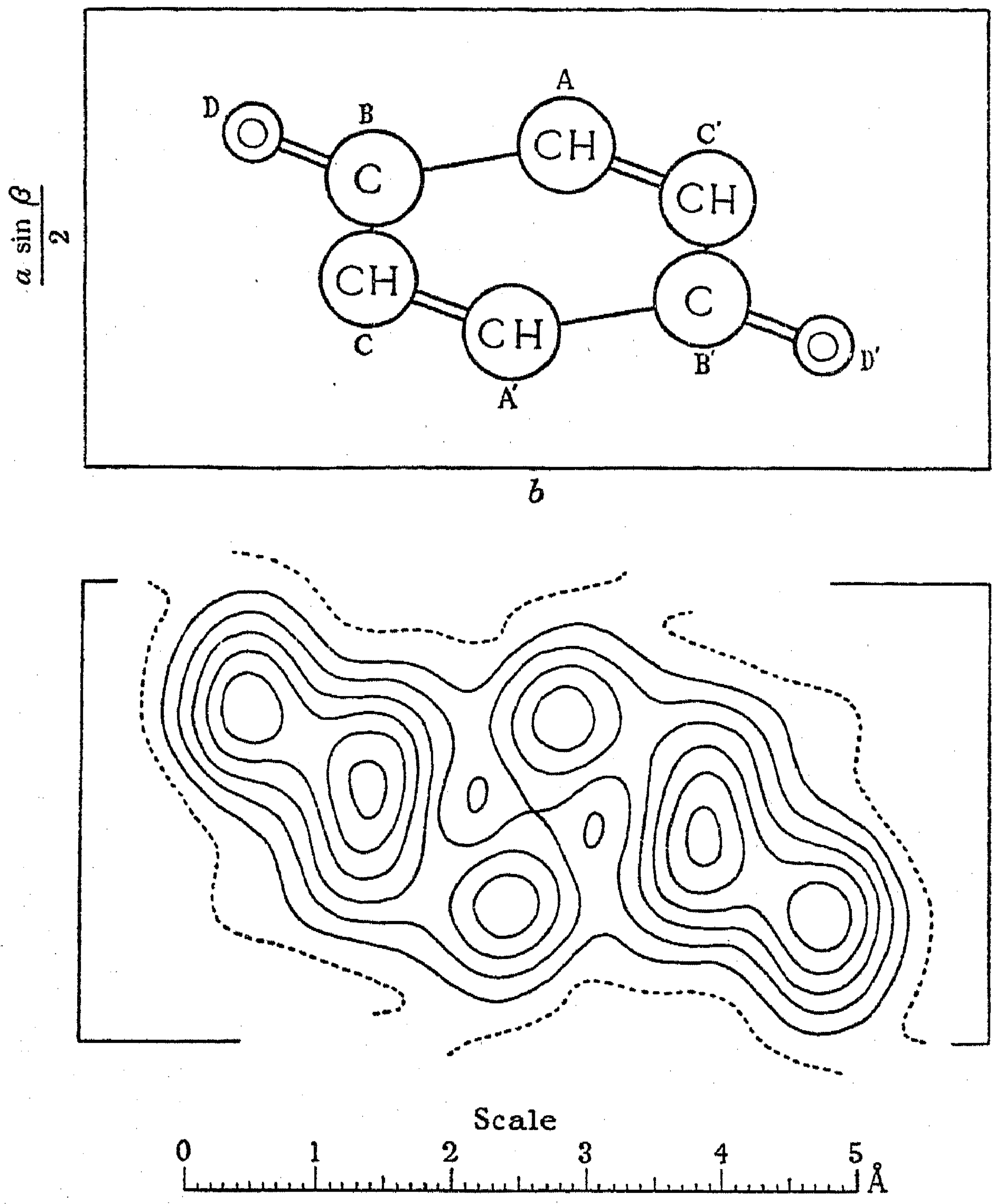


FIG. 5.—The lower figure shows the electron map of benzoquinone, projected along the *c*-axis of the cell, and the upper figure shows the relative positions of the atoms deduced from the map. The line joining the centres of A and A′ is *not* parallel to the line joining the centres of B and C, as it would be if the ring were a regular hexagon. [J. M. ROBERTSON, *Proceedings of the Royal Society*, A, 1935, vol. 150, p. 121.]

Dielectric materials in ordinary use are generally composed of molecules far more complicated than that of durene: and the arrangement of the molecules is far less regular. Nevertheless, we are able to make a useful study of such cases.

Before proceeding, however, it may be of interest to devote a few minutes to the consideration of the method of construction of an electron map. For this purpose, I will take maps of the naphthalene molecule, as this molecule lends itself well to an experimental demonstration. The naphthalene molecule ($C_{10}H_8$) has the form of a pair of hexagons as shown in Fig. 6(*b*), where the carbon atoms of one molecule are indicated by letters. One complete molecule is shown, and parts of two others. The hydrogens are not shown. In Fig. 6(*a*), the electron map is shown projected in the direction of the *a* axis of the unit cell. If this map is compared with that of Fig. 6(*b*) it will be observed that the contour lines are dense and close together where atoms overlap.

In Fig. 7 the projection is parallel to the *c* axis; the molecule is almost end on, and therefore appears in a much foreshortened form. In the contour map of Fig. 7(*a*) the overlapping is great, but this adds to the apparent simplicity and in consequence to the ease of the demonstration which I now proceed to give. (The lecturer here illustrated his remarks by practical experiments.)

If we consider the diagram of Fig. 7, showing a number of these end-on molecules, we observe that there is a periodic alternation of density parallel to various lines, of which we may take the horizontal as an example. As a first approximation, representing, in fact, the first term of a Fourier series, there is a harmonic variation of density which reaches its maximum on horizontal lines through the centres of the molecules, and its minimum in between. We may represent it on the diagram of Fig. 8 by a set of lines drawn parallel to the direction which we are considering, and indicate the density by the closeness with which we place the lines together. In the practical demonstration that I want to give, a set of threads is drawn tightly across an opening, copying the arrangement of the lines (Fig. 8). We project a shadow picture of the threads upon the screen; at the distance the shadows spread and merge together, and the effect is nearly that of a continuous harmonic variation of density.

Now it is the special capacity of the X-rays to discover and measure such harmonic variations of density in the actual crystal. The details of the theory and the corresponding experiment are given now in textbooks. The results of the experiment are the spacing and the intensity of the variation of density. We represent those by the "repeat" of the arrangement of threads and by the closeness with which they are put together.

There are any number of lines to which such harmonic variations of intensity are parallel. For instance, in Fig. 6 or Fig. 7 there are not only the horizontal side, but also the vertical side, of the dotted rectangle; also the diagonals of the rectangle, and so on. Each of these may be represented by a special arrangement of lines or threads, all of which may be seen in Fig. 9 if the diagram is held nearly level with the eye and is slowly turned round in its own plane. If now we project simultaneously the shadows of these various thread arrangements upon the screen, or superimpose them on the same sheet as in Fig. 9, we obtain a composite picture which clearly shows the main features of the true projection of the unit of pattern in the crystal. We are here using about a dozen sets. In the actual determination of the electron map of Fig. 7 about 150 separate harmonic factors were

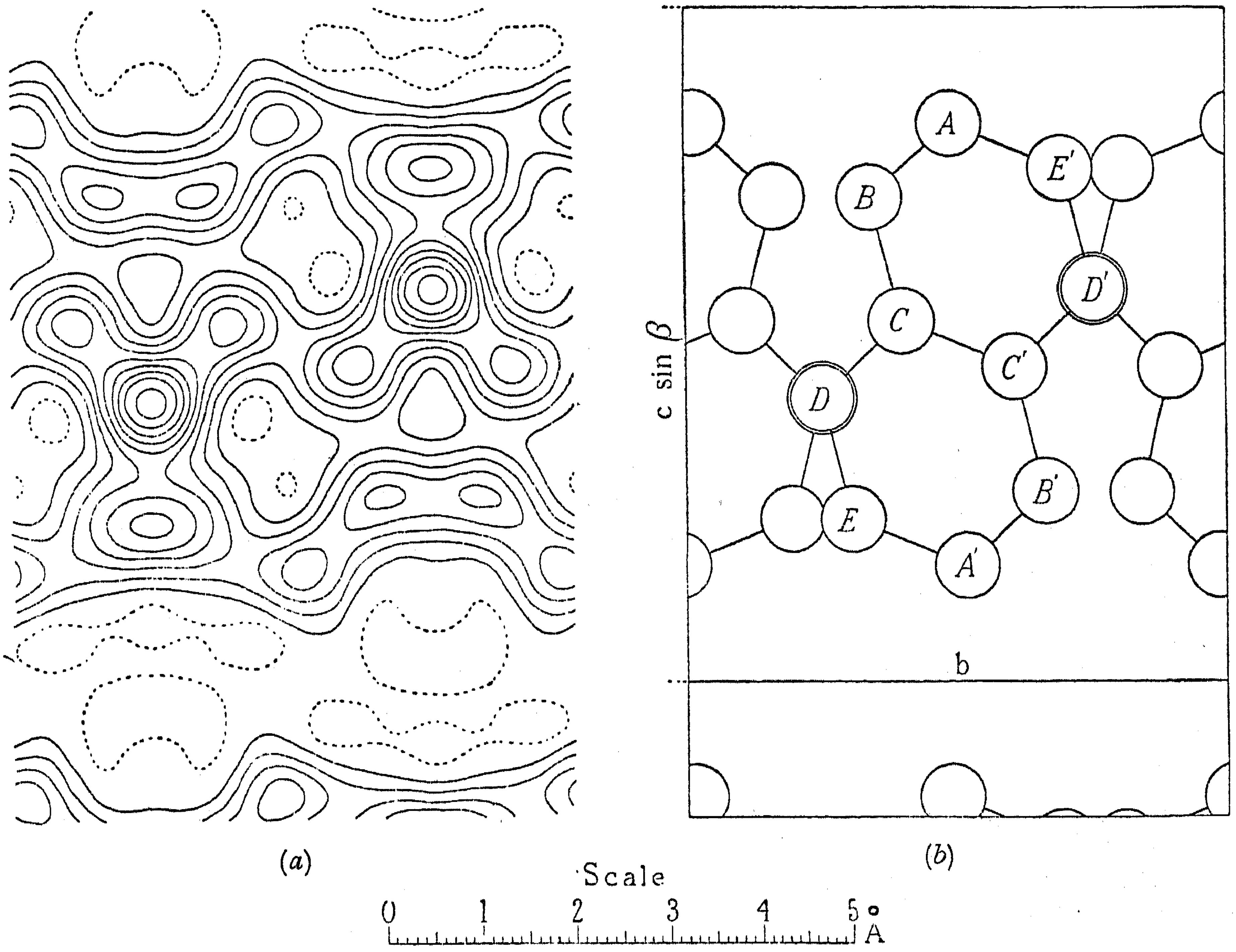


Fig. 6.—Projection of the naphthalene molecule along the *a*-axis. Each contour line represents a density increment of 1 electron per Å². The 1-electron line is dotted. [J. M. Robertson, *Proceedings of the Royal Society*, A, 1933, vol. 142, p. 682.]

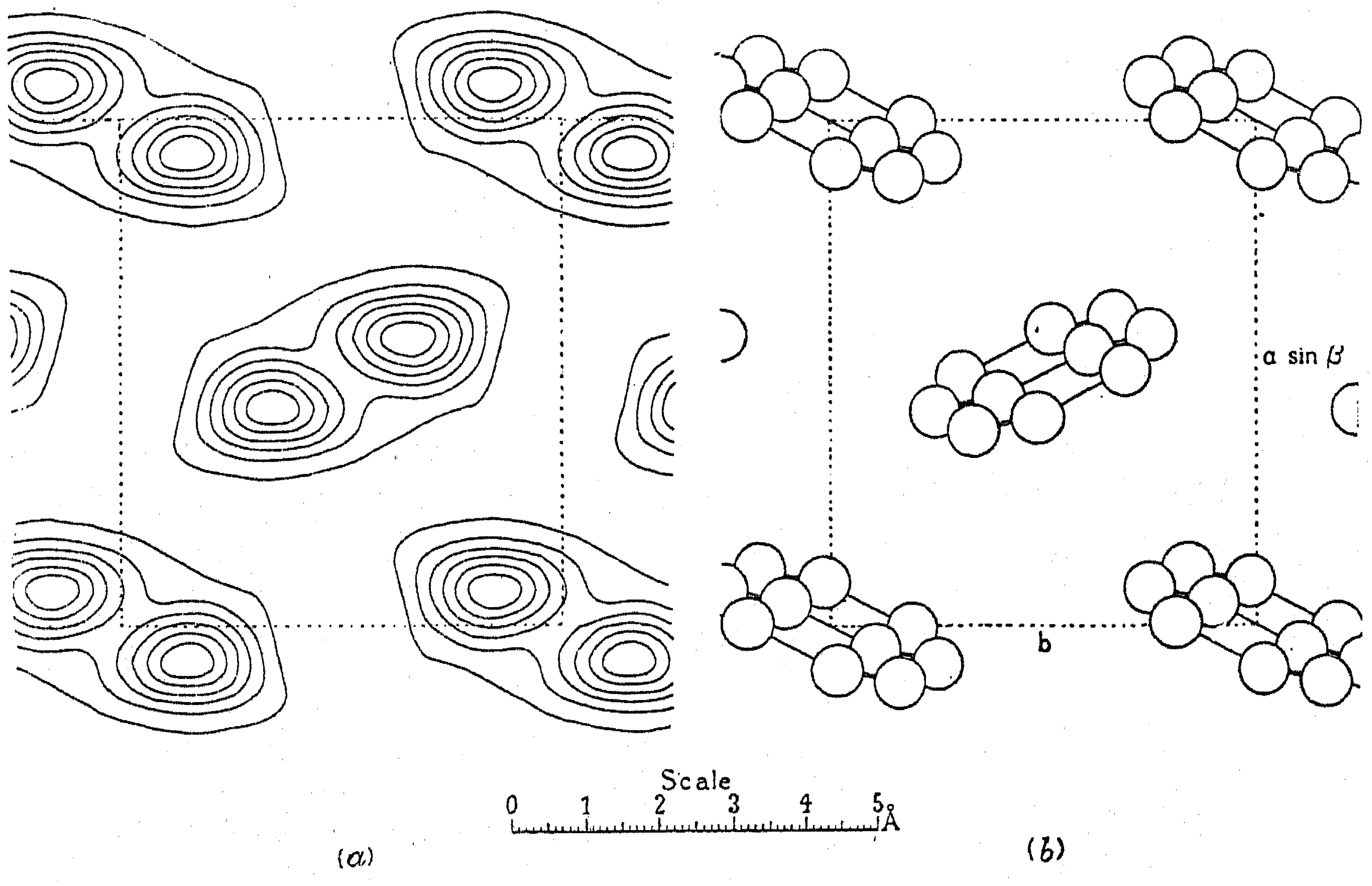


Fig. 7.—Projection along the *c*-axis, showing naphthalene molecules almost end-on. The contour lines are here graded by differences of 2 electrons per Å². [J. M. Robertson, *Proceedings of the Royal Society*, A, 1933, vol. 142, p. 685.]

measured by X-ray methods and combined by a mathematical analysis. The arithmetic is heavy, but, as I have already said, the result is worth the labour.

This method of illustration by the arrangement of lines or threads is due to Dr. Robertson, who was kind enough to prepare for me the actual experiment.

Such a method of observing in the first instance a number of separate harmonic factors and then combining them into a composite picture has its analogies with that of tidal prediction. Its principle is that of the "Fourier series" which is of such wide application in other ways.

The methods of X-ray analysis are most directly applicable to perfect crystals, and in the first instance their results were related to the structures of comparatively simple crystalline forms, determining their ideal geometrical relations. Even then it was soon evident that few substances, if any, conformed exactly to the ideal. Diamond, and Iceland spar, came near to it: but the rocksalt structure, one of the most important of the early determinations, was found to be an assemblage of very small perfect crystals, aligned to one another more or less but never completely. The effect of this departure from perfection is to blur slightly the indications, photographic or electrical, by which the structure is determined. It has not interfered with the investigations of an immense number of crystals, records of which fill whole volumes. The series of X-ray photographs shown in Figs. 10A to 10E (see Plate, facing page 744) will serve as illustrations of crystals of different degrees of regularity and composition.

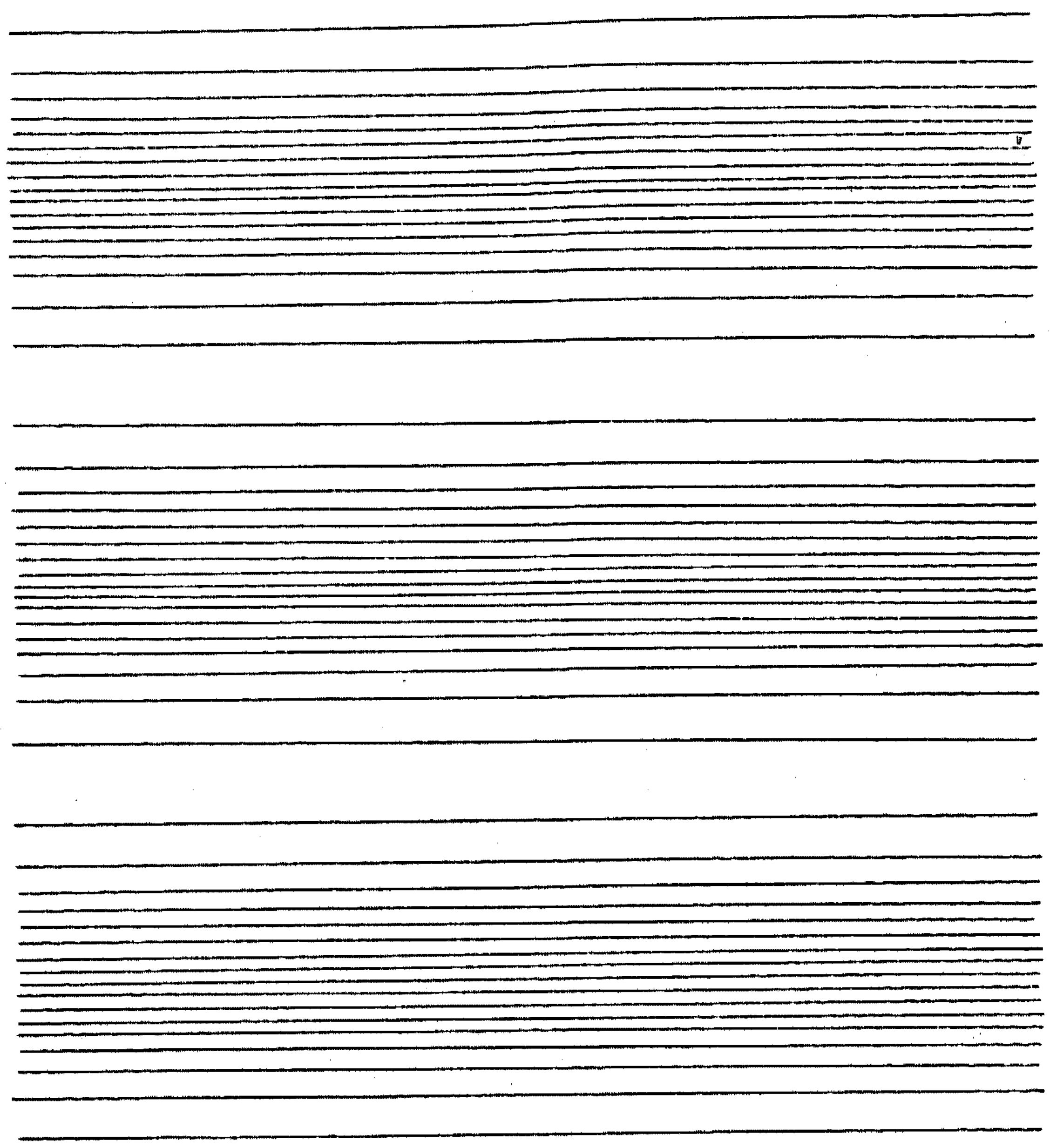


FIG. 8.—A set of horizontal lines spaced so as to represent approximately a harmonic variation of density, and in particular that harmonic variation which is the first term of a Fourier series giving the electron density in Fig. 7 averaged along lines parallel to the *b*-axis and varying with the distance from that axis.

It will be observed that vitreous silica (Fig. 10E) gives a very poor photograph consisting only of diffuse rings. Many of the substances which are much used by the electrical engineer, such as glass or bakelite, give photographs nearly or quite as indistinct. It might be thought that the X-ray methods would consequently have little to say in such cases. This, however, is not so, and for at least two reasons. The patient labours devoted to the interpretation of the simpler forms have proved a stepping-stone to the more difficult. Rules which are clearly established in the one case may certainly be accepted as applicable in the other, though their action is not so obvious. This is true, for example, of those rules governing distances and orientations to which I have already referred. And the slight indications of the less ordered structures mean much to the practised eye. Also it must not be forgotten that the X-ray indications are not the only means of information: there are other physical and chemical methods.

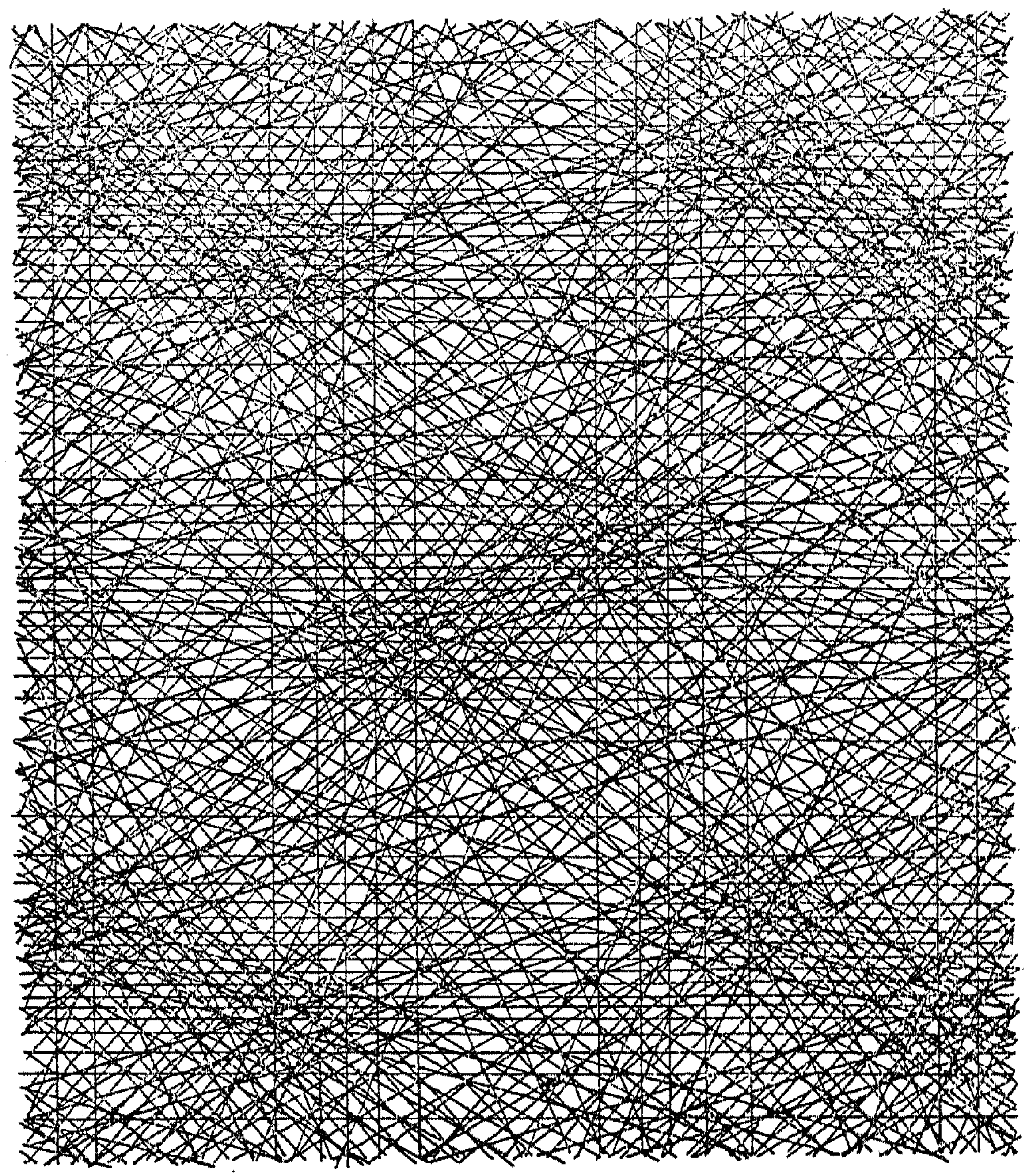


FIG. 9.—A diagram compounded of a number of sets of parallel lines, spaced harmonically as in Fig. 8, each set representing a harmonic variation of electron density. If Fig. 9 is held so that the plane of the diagram is nearly level with the eye, and the diagram is then turned round in its own plane, each set of lines will become clear in turn. The width of the "repeat" of each set is the spacing of a crystallographic plane, and the density of the lines shows the intensity of the variation of the electron density parallel to that plane. These quantities are supplied by the X-ray analysis. [J. M. ROBERTSON.]

The second reason is that the very absence of perfection can be made to tell its own story. From the size and shape of the spots in, for example, the photograph of ramie fibre, much can be inferred as to the size, form, and disposition, of the small crystallites, or regions in which there is order; or as to a general condition in which there is a greater degree of order in some directions than in others.

Consequently, the X-ray methods have been unexpectedly successful in revealing details of some complicated structures, which are of great importance to the work of the world. This applies especially to cellulose and its kin, and to the proteins. To these substances many of the materials used in the electrical industry are closely related, or at least are similar in behaviour. It is of interest, therefore, to consider what has been learnt of such materials, and we may turn our attention first of all to the work of Dr. W. T. Astbury at the Textile Physics Research Laboratory in the University of Leeds.

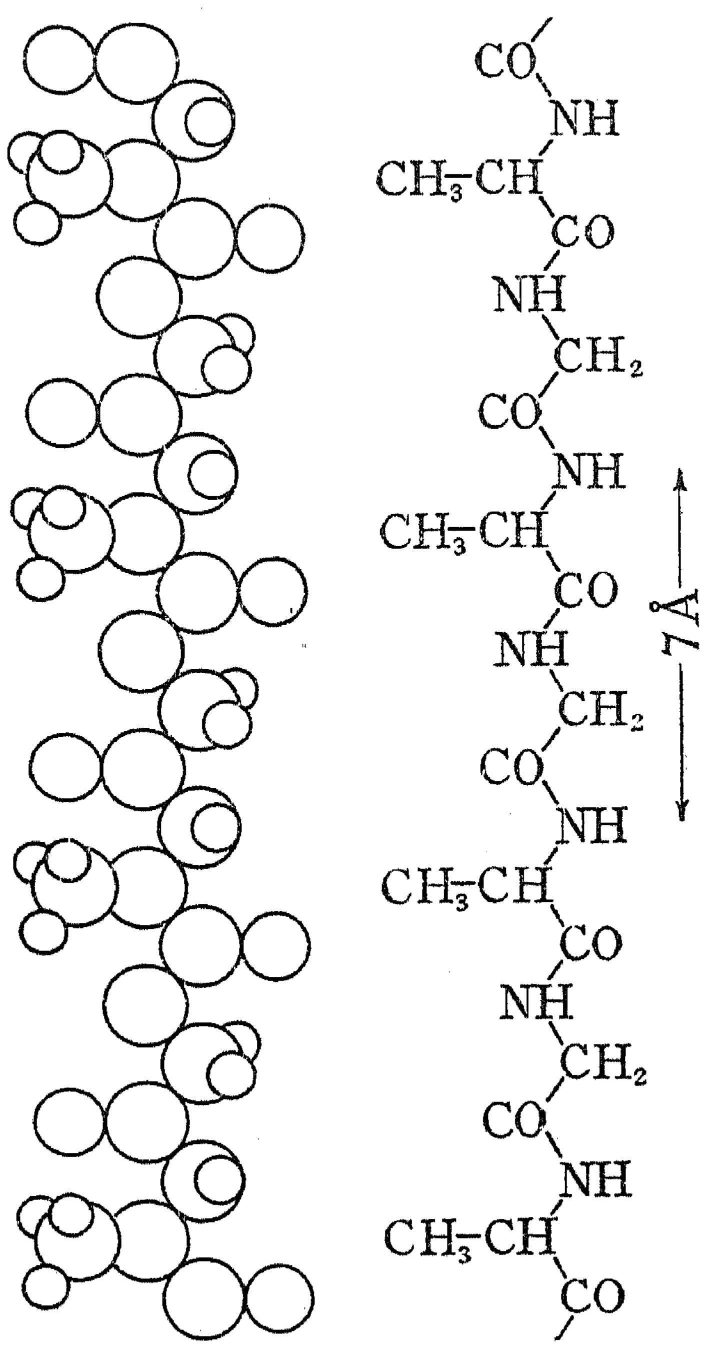
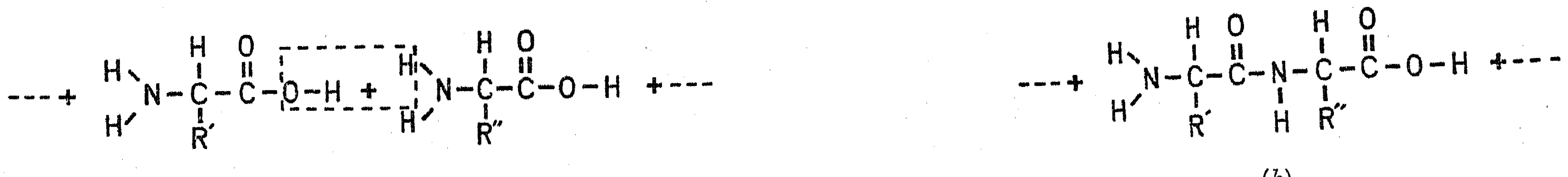


FIG. 11.—Atomic arrangement and conventional formula of part of the fibroin chain of natural silk. [ASTBURY: "Fundamentals of Fibre Structure," p. 124.]

It appears that the fundamental feature of the proteins is the zigzag arrangement of carbons and nitrogens forming a long chain of indefinite length as shown in Fig. 11. The oxygen attached to every third carbon, and the hydrogen attached to each nitrogen, are characteristics common to all proteins. The attachments to the other carbon atoms are various, however, even in one and the same chain. The chain is, in fact, derived from the successive linkage of various so-called amino-acids, in the manner shown in Figs. 12(*a*) and 12(*b*), and these acids are of many kinds. The simplest are glycine and alanine, of which, when alternated, is formed the "fibroin" which is the essential content of natural silk. The form of protein known as "keratin," which is the foundation of the fibre of hair or wool, has a far greater variety of constituents. Some seventeen are known, of which one of the most important is cystine, remarkable for the sulphur which it contains.



(*a*) (*b*)

FIG. 12.—In Fig. 12(*a*) are shown two amino-acid molecules placed side by side, which may be linked together, after the shedding of a molecule of water, to form the arrangement of Fig. 12(*b*).

If R′ is an atom of hydrogen and R″ is a methyl group (CH_3), the two molecules of Fig. 12(*a*) are glycine and alanine respectively. The chain which is formed of these molecules in alternation—as in Fig. 12(*b*)—is fibroin, the fundamental constituent of natural silk.

A protein mass is an assemblage of such chains. We have to ask next what is the manner of their arrangement. Any chain is capable of being bent or twisted into a variety of forms: it is not entirely flexible, but, as any part of the chain can be rotated about the single bond which joins it to the other part, it has a large quasi-flexibility. It can be stretched out to its full length or coiled up into a ball. Its length can therefore be greatly varied. In natural silk there is full extension and the long chains lie side by side, giving the substance its fibrous character. In wool this is not the case; the chains are considerably rumpled up when the wool is in its natural condition. The wool can, however, be stretched—a familiar fact. Compared with wool, silk is almost inextensible, because in it the chains are already at full length.

This difference between wool and silk is very remarkable, and so is the explanation given by Astbury. It would appear that the side chains in the wool have a strong attraction for one another. By these forces the molecule is made to contract, the side chains actually tying themselves together. If the wool fibre is to be stretched, many such attachments must first be broken. They must be made to "come unstuck," and for this, as so often happens, water is required. In an atmosphere of steam the length of a wool fibre can almost be doubled. If when so extended it is dried, the water molecules being thrown off by heat motion, the attachments of the side chains reassert themselves; but now they make junctions between main chains lying side by side. The chains thus acquire a more pronounced regularity, which reveals itself in the X-ray photograph.

In the normal state of the wool fibre there is always a residuum of this side-by-side arrangement, as the X-rays show. In some protein structures it is entirely absent.

There is one protein of which perfect crystals can be obtained, namely pepsin. This has been examined by Bernal,* who has shown that it consists of large globular masses arranged in an order of their own. It is probable, as Astbury has suggested, that here the chains are coiled up in a special way so that the fibrous arrangement is lost. There may be many stages between this extreme and the other in which extension is as full as possible. The change to the more fibrous and more regular forms corresponds, apparently, to that which is spoken of in the textile industries as " denaturation."

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* *Nature*, 1934, vol. 133, p. 794.

In the formation of bakelite there is much that is similar to that of the denatured protein. The molecules, phenol or cresol, are linked together by formaldehyde as shown in Fig. 13, with the shedding of water molecules. Again we observe the usefulness of water. If the linking is incomplete, and is made less so by heating, electric strain, or other means, water appears. The linkage need not be so regular as to form a crystalline pattern which would give a good X-ray photograph: it is indeed so irregular that only a very hazy picture is formed under the X-rays. The photograph is like that of the vitreous silica in Fig. 10E. There is just enough in it to reveal to the expert the prevalence in the construction of one or two important dimensions related to the benzene ring itself. We should, as Astbury says, compare its structure not to regularly interwoven fibres but to a mass of tightly felted wool. We must think of such a substance as an irregular lacework of benzene rings: with odd corners and holes and loose ends, and perhaps water molecules if it has not been thoroughly denatured, and the chance of more water molecules being formed from OH groups and hydrogen atoms which are, so to speak, left in the air. Such a felted arrangement is ascribed to glass, as in Fig. 14, which is taken from a paper by Zachariasen. Here the silicon atoms are joined together by oxygen atoms, the linking in the glass extending in all directions of space, with the one condition that each silicon is joined to four oxygens, or seeks for such an arrangement, and each oxygen is joined to two silicons.

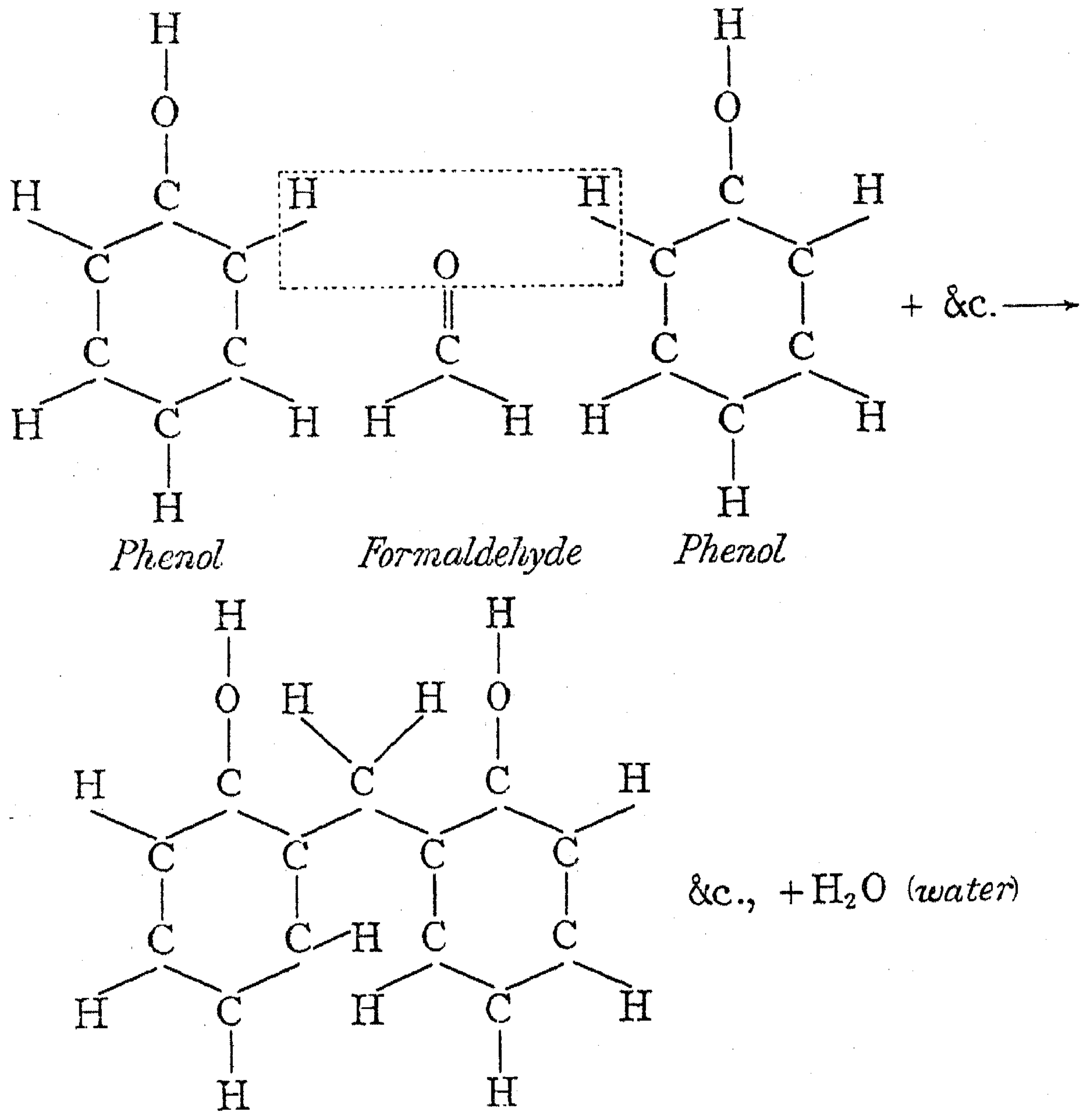

Fig. 13.—In the upper part of the diagram two phenol molecules lie side by side with a molecule of formaldehyde between them. In the lower part a combination has taken place with the shedding of one oxygen and two hydrogens, forming a molecule of water. [Astbury: *loc. cit.*, p. 52.]

In such a body there will be ions, of course. Even in a perfect crystal there are ions, which increase in numbers as the temperature is raised, as Joffé and others have shown. One would expect them to be more plentiful in the less crystalline body. The heat motions are continually testing the linkages that bind together the atoms in the molecule. As the surgings and vibrations stress the molecule now this way, now that, the forces that tend to rupture are irregularly distributed so that any one link may at some moment be brought to breaking point, or so near it that an electric force or the impact of an ion may complete the destruction. The ions will often find tracks or channels which they can follow, as indeed we know that they do. When an ion moves in this way it can spend energy by the collisions it makes. Yet as it moves out of its proper place a local electric field is set up which tends to bring it back. Such a state of things is represented by the well-known equation connecting restoring force, movement, and a viscous or frictional force proportional to the speed of movement. In such cases as come within the usual ranges of frequency of the applied electric force (the so-called radio frequencies) the motion is more than " dead-beat," so that there is no acceleration term to consider.

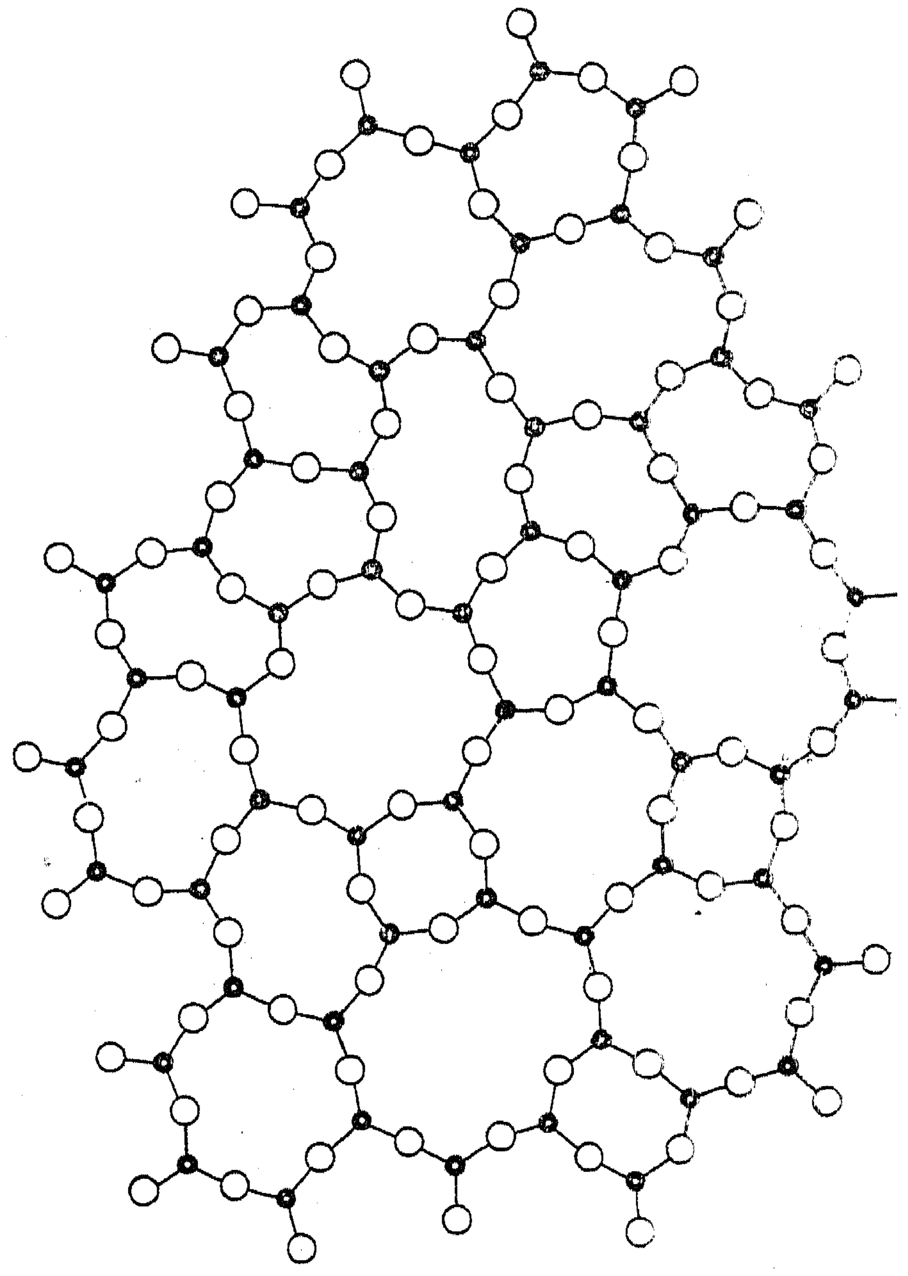

Fig. 14.—A diagram, due to Zachariasen, of the probable ways in which silicon and oxygen atoms are linked together in glass. The diagram does not show the extension in three dimensions, each silicon in the material being linked to four oxygens, whereas only three linkages are shown. The main point is the irregular lacing of the atoms together. [*Journal of the American Chemical Society*, 1932, vol. 54, p. 3846.]

We may readily suppose that the paths open to the separate ions vary widely both in length and in the ease with which they may be traversed. Under the influence of applied electric force some may continue to travel for

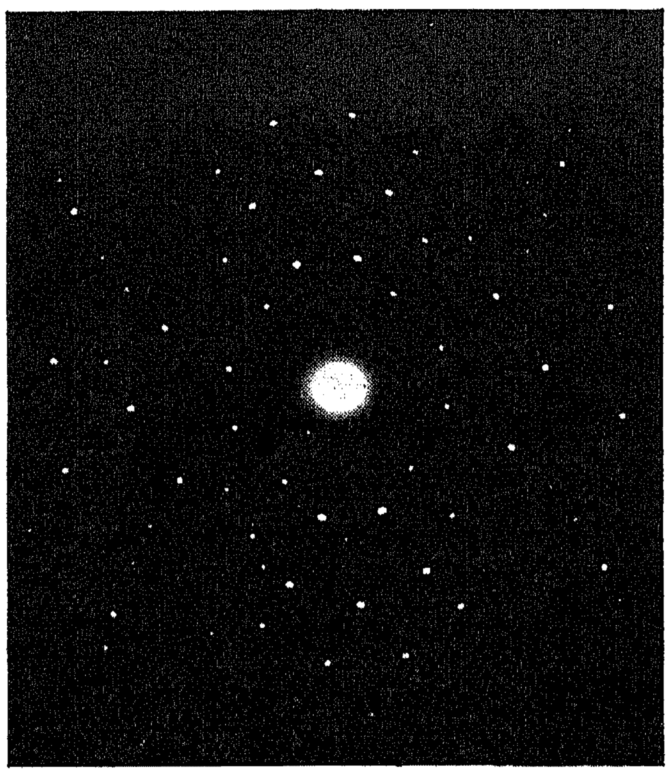

FIG. 10A.—Iron, incident radiation parallel to [110]. X-ray photograph obtained by Laue's method (heterogeneous rays). [Clark.]

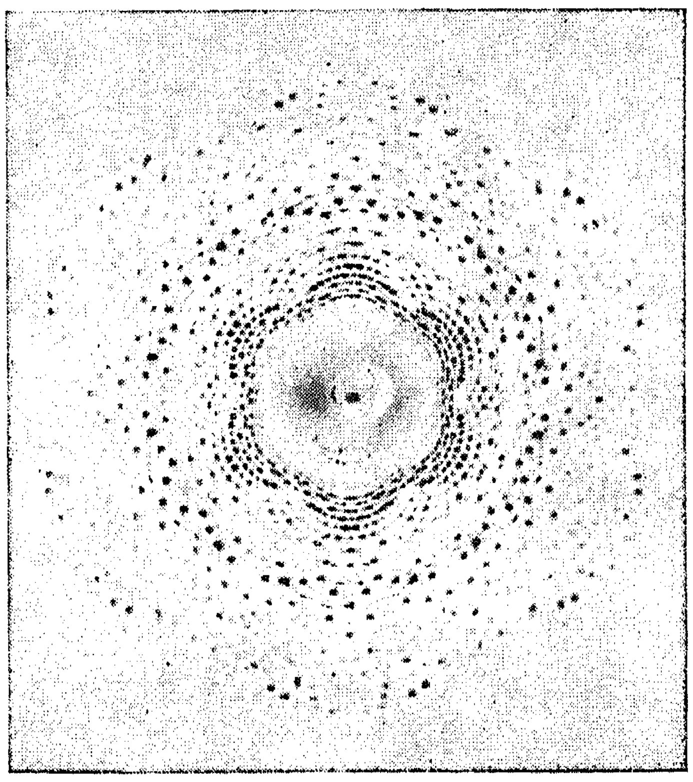

FIG. 10B.—Kaliophilite, incident radiation parallel to *c*-axis. [Bannister.]

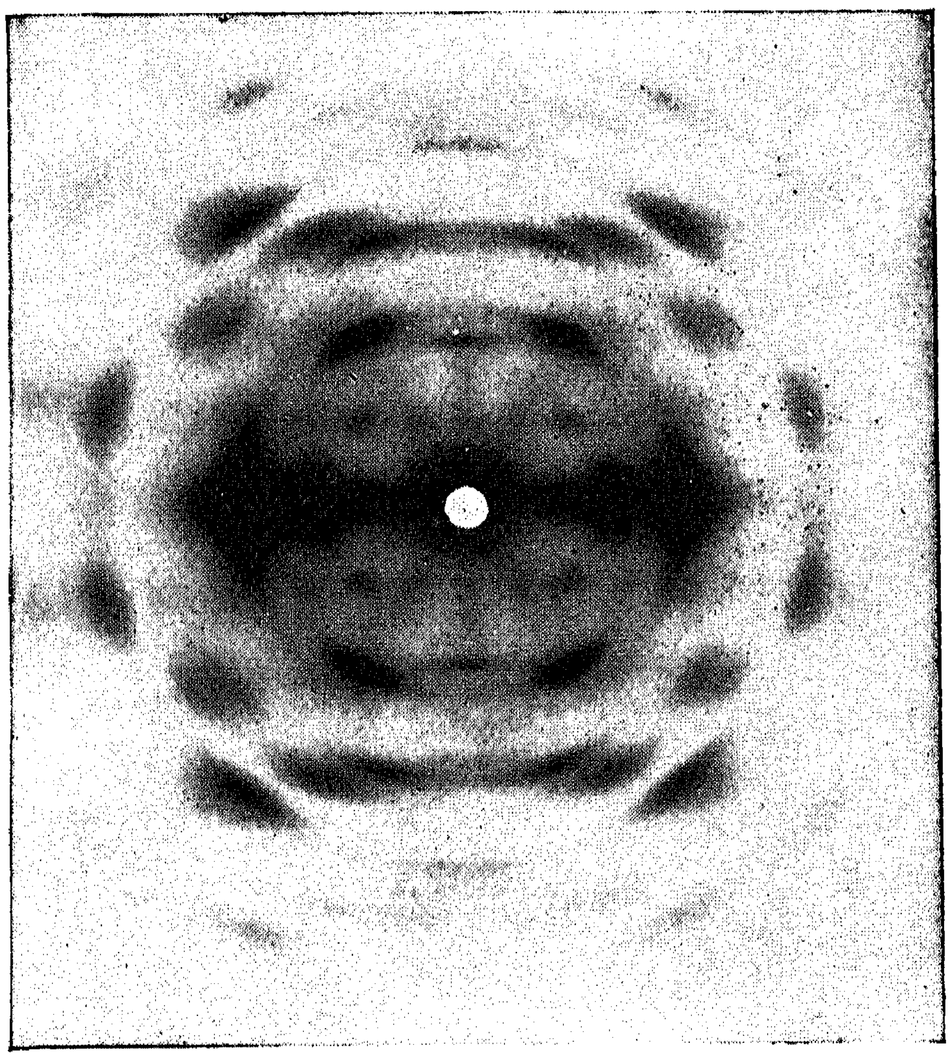

FIG. 10C.—Fibre photograph of ramie fibres (cellulose). The fibre direction is vertical. The crystals are imperfect and imperfectly arranged. Photograph obtained by means of homogeneous rays. [Astbury.]

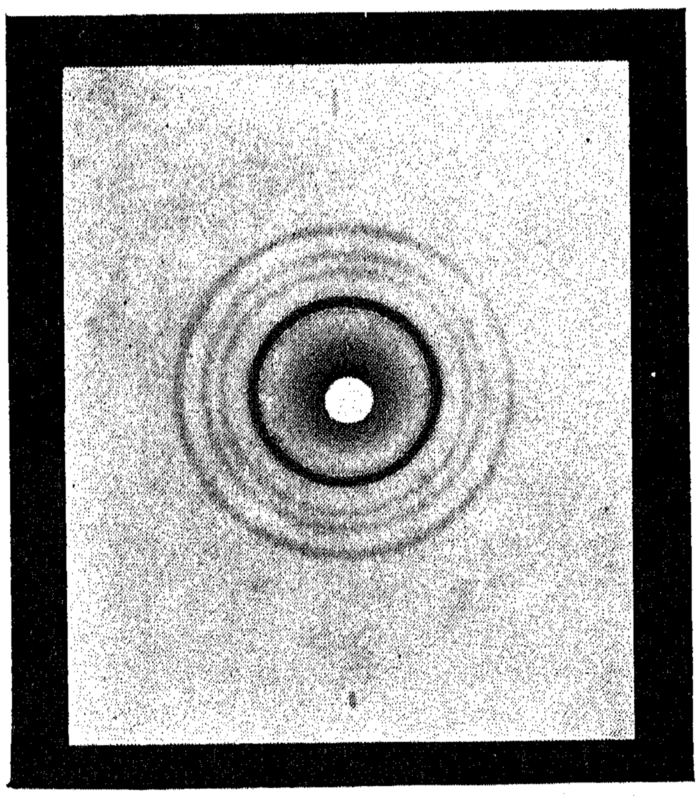

FIG. 10D.—α-Cristobalite (a powder, consisting of minute crystals). [Randall.]

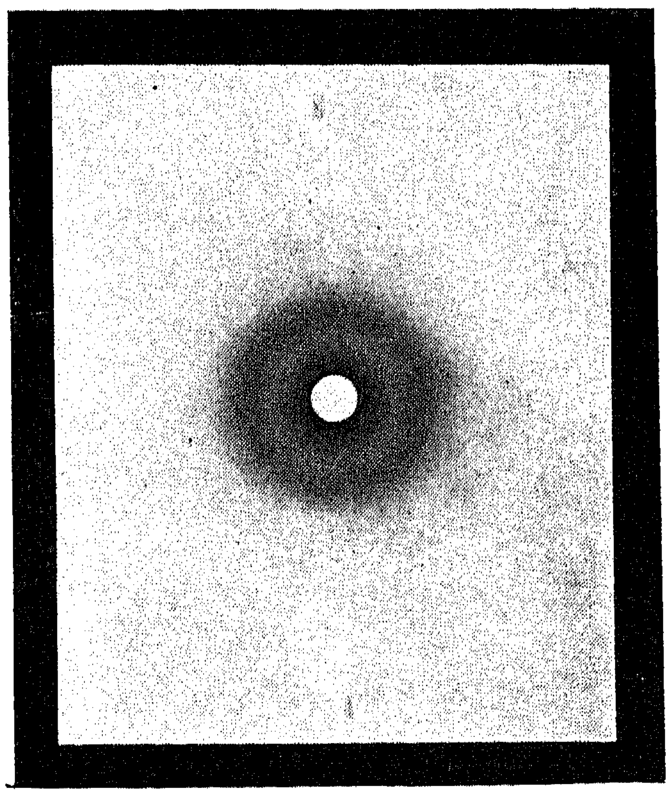

FIG. 10E.—Vitreous silica (a glass). [Randall.]

a long time, days or weeks or even longer. In other cases the motion may be quickly arrested. Some ions may travel far, as ions do in a liquid in which electrolysis is in progress: others may move for sub-microscopic distances. When a charging potential is applied to a dielectric the movement of the electrons relative to the nuclei to which they belong constitutes a true displacement current which is reversible: but the movements of the ions constitute an ionic current which may be long drawn out and may be only partly reversible.

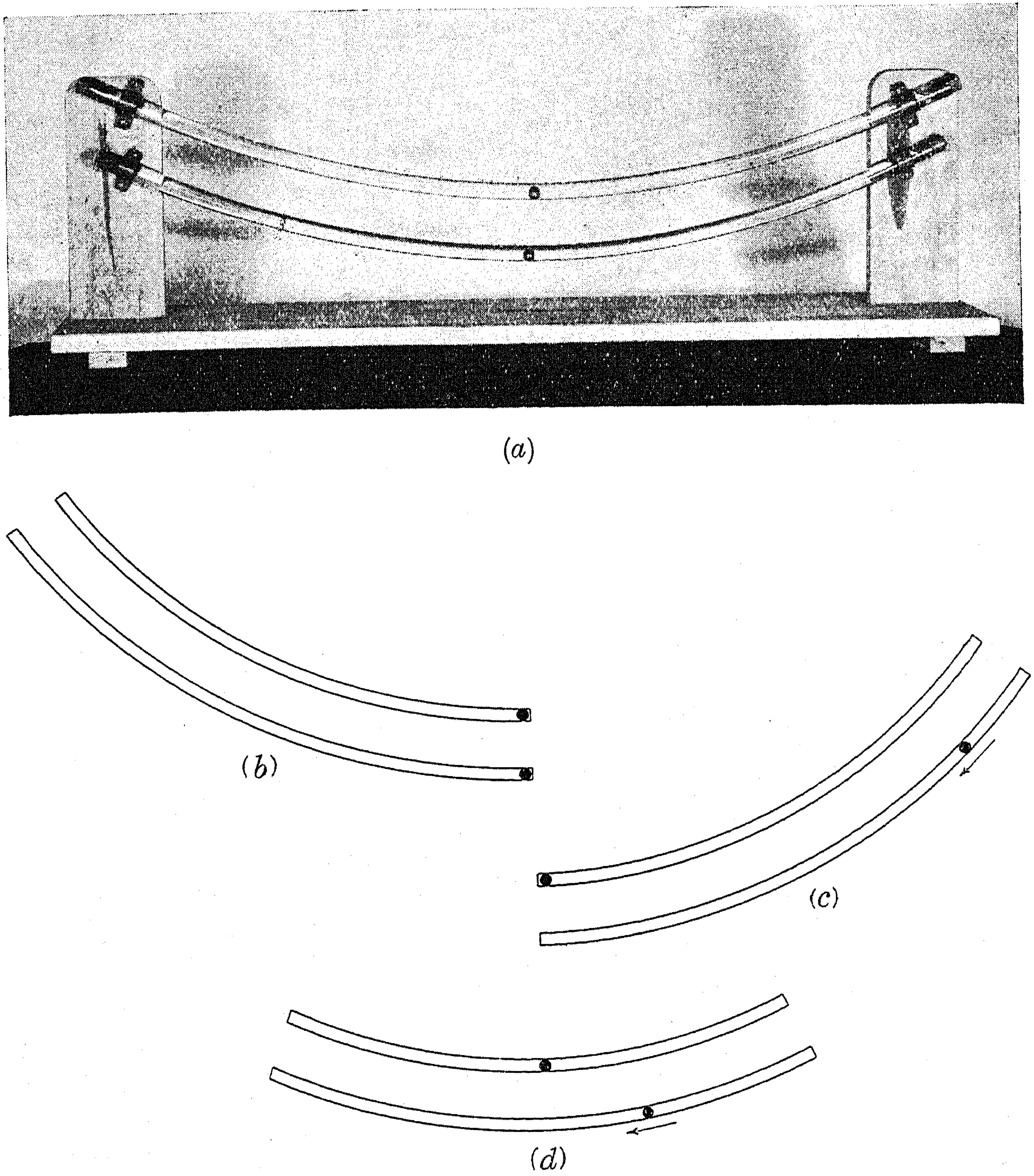

Fig. 15.—The figure shows four successive pictures of a model illustrating residual charge and discharge due to ions travelling in paths open to them. Both the curved tubes of glass contain steel balls; the upper tube is filled with water, the lower with a mixture of water and glycerine; so that, if the tubes are tilted, the balls move with velocities that depend upon liquid viscosities and are very different in the two cases. An explanation of the use of the model is given in the text.

When the applied potential is removed the displacement charge disappears as quickly as it was aroused, if opportunity is given for it to do so: but the ions may take time to come back, if they come back at all, to their original position, urged to do so by the internal electric fields due to their own displacement. Again, there will be diversity of speed; some will get back quickly and others slowly. Hence can arise the curious effect described as "charges coming out of a condenser in reverse order of that in which they were put in." The model shown in Fig. 15(*a*) will serve to illustrate the point. The two glass tubes are bent into the form of circular arcs, and are full of liquid, water in one case, a mixture of water and glycerine in the other. In each is a steel ball. When the base of the model is horizontal the balls lie in their lowest positions, midway along the tubes. When the model is tilted, as shown in Fig. 15(*b*), the balls run down to the lowest points of their tubes; one of them taking much longer to do so than the other on account of the viscosity of the glycerine mixture. This represents the movements of two ions of different speeds under a force applied for so long that both of them travel as far as they can.

Let the model be now tilted the opposite way for a short time only (Fig. 15*c*), and then brought back to its normal position (Fig. 15*d*). The ball in the water tube runs first to the other end, and then comes back to the middle of the tube fairly quickly. The ball in the glycerine tube never crosses the middle point, and is travelling back long after the first ball has come to rest. It moves more quickly when the model is in the position of Fig. 15(*c*) than in the position of Fig. 15(*d*), but is always moving in the same direction, working out the displacement imposed on it in Fig. 15(*b*). This represents the phenomenon of discharge in the reverse order of charge.

Maxwell showed that the phenomena of charge and discharge, apart from the true dielectric effects, which are practically instantaneous, are such as would be found in a stratified conductor in which the ratio of specific inductive capacity to resistance varies from layer to layer. John Hopkinson worked out the consequences of this theory in detail. The model is intended to illustrate the view that in a reasonable picture of the structure of the dielectric, based on recent determinations, there is something analogous to Maxwell's picture. Instead of separate sheets we have, however, innumerable local conditions of various kinds in which ions may move forwards and backwards under electric forces, with different resistances to their motions.

It is now known that some molecules possess permanent dipoles. Usually the dipole is due to the transfer of an electron from one atom to a neighbouring atom. As this involves a movement of the order of 1 Ångström unit, the moment of the dipole has a value of the order of $4 \cdot 77 \times 10^{-10} \times 10^{-8}$, or a small multiple of 10^{-18}.

The action of an electric field upon a liquid or gaseous dielectric containing dipoles has, of course, been studied extensively. It is of some interest to consider the effect of the presence of dipoles in a solid dielectric in the light of what is now known of crystal structure. Let us first consider briefly the theory of the dipole in the liquid, as we have been taught it by Debye. In a permanent field which has been in existence for a sufficient time the molecules of a liquid or dielectric carrying dipoles dispose themselves symmetrically about the direction of the field. The effect of collision between molecules and the consequent exchanges of energy and momentum oppose the tendency of the field, so that the molecules do not acquire complete parallelism. All that happens is that on the whole they point rather more along the field than in other directions. The polar asymmetry is, however, very small indeed. The number pointing in a direction which makes an angle θ with the field is very nearly $1 + \frac{\mu F \cos\theta}{kT}$, where μ is the dipole moment (of the order of 10^{-18}) and F, the field, may be put equal to unity (300 volts): k is Boltmann's constant ($1 \cdot 37 \times 10^{-16}$) and T is the absolute temperature. Making the numerical substitution, we find that the second term in the expression is about $2 \cdot 5 \times 10^{-5}$; and so the difference between the number pointing along the field and the number pointing the opposite way is only a very small fraction of the whole. Nevertheless, the electric moment of the whole is by no means small, because the number of dipoles is great. This means that the impressed force has only a very slight effect on the alignment of the molecules. It is as if the molecules were trying, under the influence of the impressed force, to turn in a very viscous medium. The impressed force is spent almost entirely in efforts to overcome that viscosity: the limiting speed of rotation which is generated is realized so quickly that acceleration is not worth consideration, and inertia of the molecule does not usually enter into the reckoning.

If the impressed force is removed, the system rights itself and the slight asymmetry disappears in time. This delay is measured by what is called the time of relaxation, which is defined as the time of falling to $1/e$ of its initial value. This time multiplied by 10^{10} may be of the order, in liquids, of a few seconds.*

If an alternating field of force is applied the arrangement of molecules forms and reverses its form as often as the force, but is not, of course, in phase with it, and there is consequently a development of heat. The maximum development of heat occurs when the time of an oscillation is of the order of the time of relaxation. If the frequency is very small, the resistance of viscosity has little opportunity to act; if it is very large, the molecules have no time to change their positions and viscosity effects disappear in this case also.

When we turn our attention to the solid we observe at once that obvious characteristics of the solid phase affect both the application of the Debye theory and the magnitude of the effect to be expected. Before we proceed to examine these differences, however, it may be interesting to consider an experiment which illustrates the existence of dipoles in a crystal. For this purpose we must choose a crystal which consists of dipolar molecules so arranged that the dipoles do not balance one another. It would be useless to choose, for example, a crystal of a fatty acid, because the unit of pattern contains two molecules arranged about a centre of symmetry, so that although each molecule contains an OH dipole, the two dipoles balance one another in every direction. It would be equally a mistake to use a crystal of para-dinitrobenzene because the two nitro groups in each molecule might be expected to balance one another, and in fact experiment shows that the balance is, at least, nearly perfect. In consequence of these arrangements, neither of these crystals would serve our purpose.

Consider, however, the crystalline form of resorcinol (see Fig. 16). The individual molecule is dipolar because the two OH dipoles are in "meta" positions with respect to each other, and therefore do not balance. There are four molecules in the unit of pattern. They are arranged so that the dipoles of the four molecules balance across each of two planes which are at right angles to one another: in Fig. 16 the two planes are perpendicular to the plane of the paper. There is *not*, however, a balance across the plane of the paper; four more molecules would be required for that, placed so as to be the reflection of the first four in a plane parallel to that of the paper. In the absence of the second four, the arrangement is polar across the one plane. It forms an "electret," to use a term devised by Eguchi to express an analogy with "magnet." It is true that we do not find a resorcinol crystal to behave under ordinary circumstances like a magnet. Two such crystals do not possess opposite poles with which we may show that likes repel and unlikes attract. This want of similarity to the magnet, however, is due to the fact that ions have been collected and arranged so as to balance the moment of the electret; no analogous behaviour can be realized in the magnetic case.

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* P. Debye: "Polar Molecules," p. 108.

If, however, we dip two resorcinol crystals in liquid air, their electrical moment is made obvious by their mutual attractions and repulsions. The change of temperature has slightly altered the arrangement of the four molecules in the unit cell, the moment is altered in amount, and the compensation by the ionic charges is destroyed. If a crystal is left long enough in its chilled condition, the balance is restored by a readjustment of ionic charges, and then, if it is allowed to warm up, the resorcinol crystal becomes charged in the opposite direction, and further movements of ions are required to bring back the crystal to its original condition. By means of X-rays we can provide supplies of ions which hasten the readjustments. The progress of readjustment is rather slow, which suggests that internal movement of the ions is important. An extremely small change in the orientation of the molecules accounts for the magnitude of the observed charges.

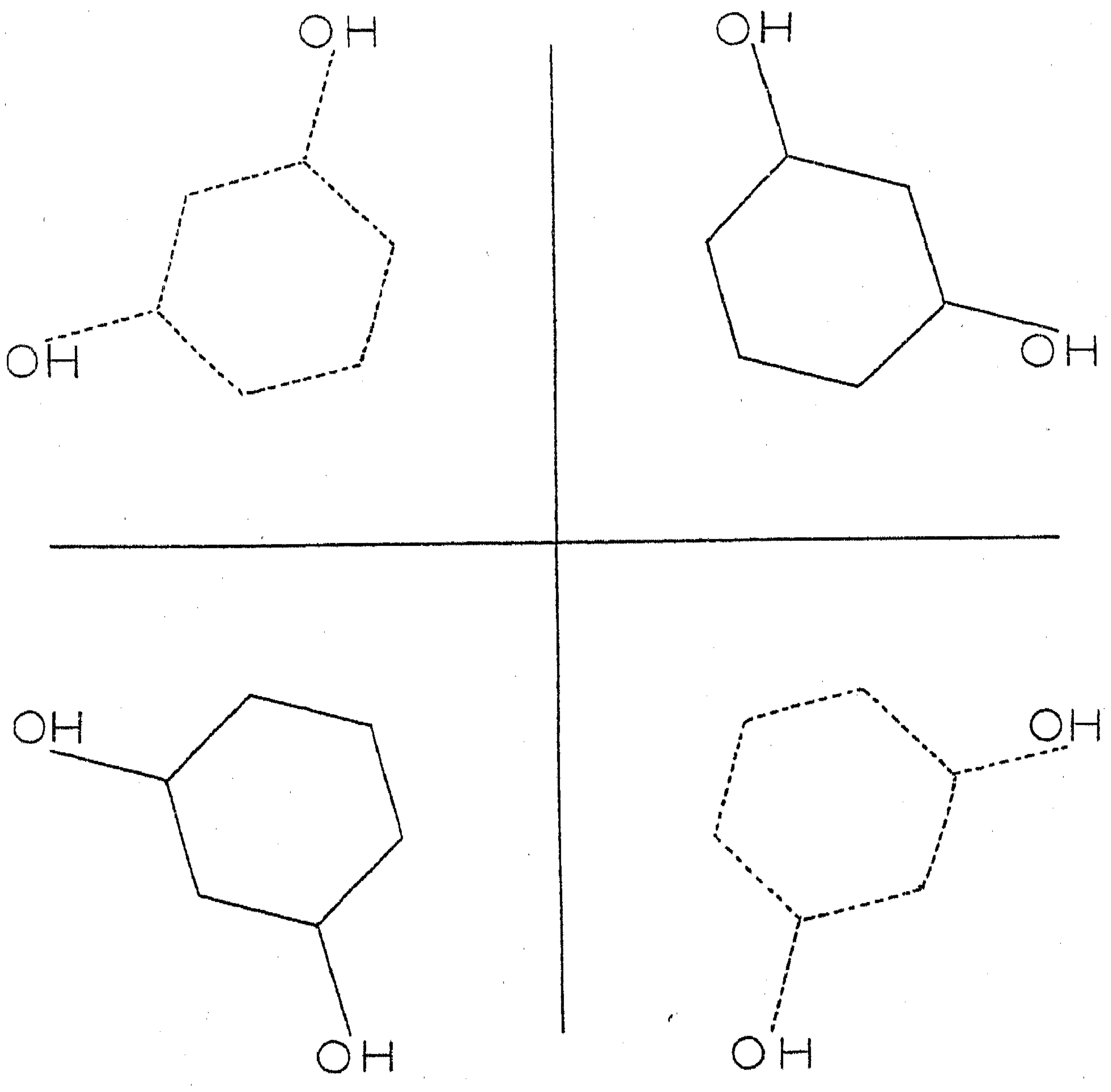

FIG. 16.—A sketch showing the symmetry of the arrangement of the four molecules of resorcinol which occupy the unit cell of the crystal. The hexagon has carbon atoms at its corners. To four of the carbons, hydrogens are attached; to the other two, hydroxyl groups: the latter are shown. The centres of the continuous-line hexagons being supposed to be in the plane of the paper, the centres of the dotted hexagons are behind that plane. The arrangement gives symmetry about planes normal to the plane of the paper and passing through the rectangular axes shown in the sketch. There is no symmetry about the plane of the paper. The relative distances and orientations of the molecules are not to be inferred from the sketch; they are, in fact, undetermined.

Returning now to our comparison of the probable effect of the presence of dipoles upon the behaviour of a solid dielectric, we observe that the molecules in the solid are comparatively fixed in position. Any movement involves elastic stresses of which the Debye theory, as applied to liquids, takes no account. The maximum couple that can be exerted by a field of 1 electrostatic unit (300 volts) is between 10^{-17} and 10^{-18} dyne-centimetre, which figure also expresses the half of the work that can be spent in turning the dipole right round so as to face the opposite way. In a liquid, as we have seen, such forces can produce only a very slight change in the average orientation of the molecules. In a solid, the effect must be far less. A dipole may be so rigidly attached to the molecule that any change in its orientation involves either the movement of the molecule as a whole or a strain between the dipole and the rest of the molecule. The former effect must occur far less readily in the solid than in the liquid. The latter would also appear to be very small, because it requires about 10^{-12} erg to break an atomic bond, and therefore an expenditure of 10^{-18} erg can have very little effect. It is possible, however, for some dipoles to alter their orientation with respect to the molecule without such strain. If, for example, we take the case of an OH dipole attached to a benzene ring, the bond between the O and the H is inclined at a considerable angle to that which connects the oxygen with the ring, and the dipole can therefore revolve about the latter bond so that the orientation of its moment is altered. Of course, any such motion must be hindered by the action of the surrounding molecules of the solid. There does not seem to be sufficient knowledge of these actions to make it possible to calculate their amount, but one would expect them to be very effective in preventing change.

On the whole, it would seem safe to assume that the dipole effect in the solid must be far less than in the liquid. Moreover, one would expect any such effect to have a short " time of relaxation ": it would not drag on over long periods such as are found in the phenomena of " residual " charge and discharge. It would be more readily detected by high-frequency changes of potential comparable with the infra-red frequencies. Residual charges and discharges are more likely to be due to ionic movements, which are known to be possible and to occur.

We have already seen that the nature of the assemblage of molecules in a dielectric may well be responsible for the presence both of discontinuities and cavities, and of ions which can therein find room to move. Recent work on the relations between the structure of crystals and their properties has strengthened this conception. Even in crystals in which no irregularities are to be observed optically, nor any variation in the crystalline pattern revealed by X-ray methods, there are certainly flaws and discontinuities. They are generally too small to be detected by the microscope. The X-rays show that the mass is made up of minute crystals perfect individually but not quite in perfect alignment, and therefore separated by breaks of various kinds. The existence and distribution of such discontinuities depend on the mode of formation of the crystal. Thus, for example, rock-salt, an excellent example of a " mosaic " crystal, contains fewer discontinuities when formed from the melt than from solution. There is no difference in the appearance of the whole crystal, nor in the details of the structure of the separate crystals of the conglomerate.

The differences are found in such qualities as mechanical strength and heat conductivity, properties termed by Smekal "sensitive properties" as compared with the atomic distances and orientations in the crystal, which are "insensitive" to the circumstances under which the crystal was formed. The sensitive properties are affected by mechanical treatment such as "cold working," and by heat treatment such as annealing.

There has been much discussion as to the existence of any regularity in the distribution of the flaws in the crystal. Some have supposed that there is enough regularity to justify the assumption of a super-structure, of which the unit of pattern is built on a scale too large to be measured by X-ray methods. Others believe that the distribution of the small crystals in size and orientation is purely statistical, showing small deviations from mean values.

It is generally supposed that this super-structure—whether regular and intrinsic or accidental and superimposed—is responsible for the low value of the tensile strength, and for its wide variations. It has been suggested also that similar low values and variations of electric strength are due to the same cause.

In concluding this lecture I should like to repeat that I am conscious of the risk which I run when I endeavour to suggest ways in which our X-ray work may possibly affect your own investigations of dielectric phenomena. My belief is that it is worth while to speculate in order to be suggestive. The determination of atomic and molecular spacings and orientations must eventually be necessary to the full understanding of the properties of dielectrics, and the X-ray work is sufficiently advanced to make preliminary attempts to apply them.

DESIGN DATA IN RURAL DISTRIBUTION LINES.

By R. DEAN, Associate Member.

(*Paper first received* 29*th August*, 1933, *and in final form* 22*nd November*, 1935; *read before the* TRANSMISSION SECTION 15*th May*, 1935)

SUMMARY.

The available data relating to the detail design of rural distribution lines are very limited and scattered, and only to be found by prolonged search through numerous technical journals, manufacturers' lists, and the usual textbooks. They refer primarily to individual fittings, or alternatively to basic principles.

Although the principles involved are in the main simple, the calculations are often in their practical application lengthy and tedious.

All overhead transmission or distribution lines in this country must be designed to comply with the Regulations for Overhead Lines El.C. 53, prescribed by the Electricity Commissioners for securing the safety of the public. The basic factors of design are therefore common to various types of construction, even though the detail design may vary considerably.

The prime purpose of this paper is to present information relating to the detail design of overhead lines for rural distribution, in a form which it is hoped may prove easy of application, and thus obviate many of the tedious calculations above referred to.

An attempt has been made to simplify and clarify the application of basic principles by means of a series of tables and graphs, which enable one to determine at a glance the final results, in much the same way as the complexities of the properties of steam have been clarified in the entropy diagram, or the effect of money rates operating over a number of years, as readily seen in interest or discount tables.

The form of presentation of much of the data is original and no attempt has been made to include the usually accepted formulæ or fundamental principles, details of which may be found in any reliable textbook. Similarly, details of the official regulations relating to overhead lines are not included, as they are covered in the Electricity Commissioners' Regulations El.C. 53 and Explanatory Memorandum El.C. 53A.

The paper is divided into two parts, the first being a series of tables and graphs covering various aspects of line design, the second describing a number of practical details of design which have proved efficient in service.

It is hoped that the form of presentation may appeal to the busy engineer, and in particular to those who may be responsible for the design and erection of both high- and low-voltage overhead distribution lines.

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Acknowledgments.

INTRODUCTION.

During the past 10 years the distribution of electricity by means of overhead lines has made rapid progress, but, notwithstanding this, in nearly 80 per cent of the occupied rural areas of England supplies are not yet available. Thus, although most of the work on the overhead main transmission lines in connection with the Central Electricity Board's schemes has now been completed, there is still an enormous amount of development work to be done in regard to both high- and low-voltage distribution in the rural areas.

The general aspects of rural distribution have been covered by a number of recent papers read before the Institution.[*] The present paper is intended to deal primarily in tabular and graphical form with the detail design of high- and low-voltage rural distribution lines.

It is generally accepted amongst engineers that there is a wide gap between academic or basic principles, and the finished article. In the case of products manufactured in a workshop, this gap is usually bridged by what has come to be known as "shop practice." As a result of experience, often acquired in a hard school or at heavy cost, certain standards are evolved and methods adopted which considerably simplify the application of fundamental principles. These "short cuts" help to bridge the gap above referred to. In the design stage the short cuts usually take the form of tables or graphs, and later may be in the form of drawings. As is to be expected, they are mainly found in connection with the older branches of industry, e.g. steam tables for engineers, and interest, discount, or wages tables for accountants. The more modern an industry, or even branch of an old-established industry, the less is the likelihood of such information having become standardized and circulated in some form convenient of application.

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[*] (1) E. W. DICKINSON and H. W. GRIMMITT: "The Design of a Distribution System in a Rural Area," *Journal I.E.E.*, 1932, vol. 70, p. 189.
(2) C. R. WESTLAKE: "Electrical Development of Northern Ireland," *ibid.*, 1935, vol. 77, p. 245.
(3) J. A. SUMNER: "Private Plants and Public Supply Tariffs," *ibid.*, 1935, vol. 77, p. 310.

The bringing into operation of the Electricity Supply Act (1926) has resulted in the centralization of generation, so that electricity must be supplied over far larger areas. The transmission and distribution of electrical energy have thus become of greatly increasing importance. In the case of generation, methods and costs have been carefully recorded over a greater number of years, with the result that emphasis is laid on differences of a few per cent in thermal efficiencies between the various stations. Such varied devices as air heaters and preheaters; reheaters of various kinds; regenerating processes, such as feed heating with exhaust steam from auxiliaries; multi-stage bleeding of turbines; air and water jacketing of furnace walls; are installed in an endeavour to save even a few per cent on the coal bill. Owing to the predominating effect of capital charges, these devices may only result in a saving of little over 1 per cent for energy at the station busbars. Already the capital sunk in distribution is considerably in excess of that in generation, and at the present time the rate of further annual expenditure is approximately 3 times greater in the case of distribution. It is generally recognized that this branch of our industry offers the greater field for development and scope for those technical and practical improvements which should result in increased reliability and economy.

Part I. Design Statistics.

(1) GENERAL ASPECTS OF DESIGN.

A high-tension distribution voltage of 11 000 volts has been generally accepted, and has proved economical for many rural schemes where the loads are small and occur at frequent intervals. Where heavier loads are anticipated, or the normal loads are particularly scattered over a wide area, the use of the higher distribution voltage of 33 kV is rapidly gaining favour on new schemes, and is to be recommended both on economical grounds and as a means of avoiding troubles due to voltage regulation on the high-voltage line.

In the case of existing systems where the lower voltage of 11 kV is already in use, the tendency is to erect additional single-circuit 3-phase lines, each following a different route, so as to embrace the greatest area and possibly to form ring mains, rather than to erect double-circuit routes for the supply to the more heavily loaded centres. Thus, in practically all cases high-voltage rural distribution lines are unlikely to exceed single-circuit 3-phase lines of 0·15 sq. in. copper or its equivalent. Such lines will satisfactorily deal with the power involved, without undue voltage-drop.*

For the mechanical loadings which conductors of this size involve on the medium-span lengths now in general use, the author recommends the use of single wood poles, especially where pin-type insulators are to be used. Although wood poles are the only type dealt with in the paper, much of the general information given is applicable to poles of other types. Both reinforced-concrete and fabricated-steel poles have hitherto been found to be from 10 to 15 per cent dearer than wood poles, for the type of lines under consideration. Since the coming of the relaxation in the factor of safety of wood poles from 10 : 1 to 3·5 : 1, the question of providing adequate earth foundations has become increasingly important. The author has prepared a series of graphs relating to foundations for (*a*) single poles only, (*b*) single poles with one kicking block, and (*c*) single poles with two kicking blocks, which should cover most conditions likely to arise in practice.

For the transmission of heavier power loads the only conductors normally used are copper or steel-cored aluminium. Rural distribution, however, introduces the problem of transmitting quite small currents relatively long distances, and thus the conductor is often selected primarily for its high mechanical strength rather than for its actual current-carrying capacity, with the result that quite a number of different sizes and classes of conductor material are in everyday use.

In the paper various classes of conductors are considered for high-voltage lines, and graphs (Figs. 5A to 5F) showing the result at a glance have been prepared for those in most general use. In the case of low-voltage lines, details are submitted for hard-drawn copper conductors only, as copper, particularly at its present price, is in the author's opinion the only conductor to be seriously considered. The use of stranded conductors for low-voltage lines is recommended. In view of the large number of service tappings and jumper connections on low-voltage routes, 7-strand conductors are preferable to 3-strand, as they offer a much better surface for clamp-type connectors, without the disadvantages of solid conductors.

The three main sizes of low-voltage conductors considered in the paper are 0·1 sq. in. (7/·136), 0·0585 sq. in. (7/·104), and 0·0221 sq. in. (7/·064), the latter being used for service lines, or as a public-lighting switch wire. The 0·0585-sq. in. size has been selected in preference to the usual 0·05-sq. in. to help offset the additional voltage-drop on overhead lines in comparison with underground cables, where the minimum size of distributor which it is now permissible to lay on new schemes is 0·05 sq. in.

The usefulness of many graphs has in the past been largely lost owing to their easy interpretation only being possible to the person originally designing them. In order to overcome this defect and to facilitate the use of the various graphs and tables contained in this paper, a brief survey of their application will now be given.

(2) WIND PRESSURES AND WEIGHTS OF ICE COVERING ON CONDUCTORS.

Fig. 1.

To determine the weight of ice per foot of any wire having a bare diameter up to 0·9 in., read off the diameter along the lower horizontal scale, and opposite the point on the graph vertically above, read on the left-hand vertical scale the weight of ice per foot; thus the weight per foot of a $\frac{3}{8}$-in. radial thickness of ice on a wire having a bare diameter of 0·35 sq. in. is 0·34 lb., while that of a $\frac{3}{16}$-in. ice thickness is 0·126 lb. Similarly the wind pressure per foot run of an ice-covered wire having an overall diameter of, say, 1·1 in. is found by reading the diameter along the top horizontal scale and reading off on the right-hand vertical scale the wind pressure in pounds per foot run, namely 0·733.

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* See Fig. 14 in paper by Messrs. Dickinson and Grimmitt (*loc. cit.*).

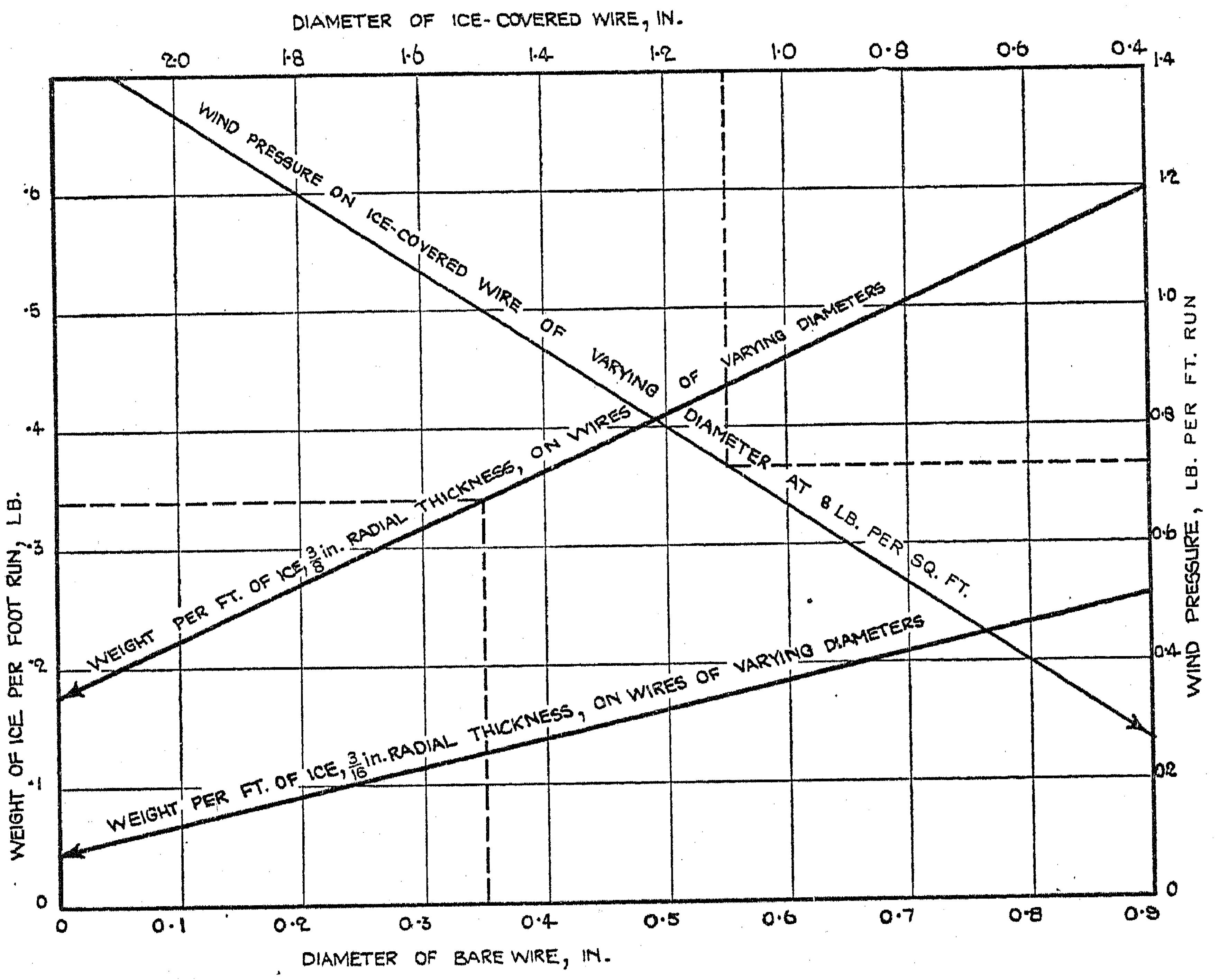

FIG. 1.

Fig. 2.

The transverse load on practically any type of conductor on various span lengths up to 900 ft. when subject to a $\frac{3}{8}$-in. radial thickness of ice and a wind pressure of 8 lb. per sq. in. on the projected area (to comply with Regulations El.C. 53) can be read directly from Fig. 2. The upper values on the horizontal scale at the foot of the graph apply in this case. For low-voltage lines where only $\frac{3}{16}$-in. radial thickness of ice is involved, the vertical values to the right of the graph and the lower values on the horizontal scale at the foot of the graph, should be read. Two examples will now be given of the use of Fig. 2.

High-voltage line, 8-lb. per sq. in. wind and $\frac{3}{8}$-in. ice loading.—To find the transverse load per conductor on a 400-ft. span of 0·1-sq. in. (copper equivalent) steel-cored aluminium round stranded conductor, in the vertical column to the left of Fig. 2 headed "Steel-cored Aluminium Round Conductors," select 0·1 sq. in., and follow along horizontally to the right, to the diagonal marked "400 ft." at the top of the figure. Immediately below the point of intersection read off the wind load on the upper scale at the foot of the graph, viz. 352 lb. approximately.

Low-voltage line, 8-lb. per sq. in. wind and $\frac{3}{16}$-in. ice loading.—To find the transverse load on a 180-ft. span of 0·1-sq. in. (7/·136) hard-drawn copper conductor, in the vertical column to the right of the figure select 0·1 sq. in. and follow along horizontally to the left to the diagonal marked "180 ft." at the top of the figure. Immediately below the point of intersection read off the wind load on the lower scale at the foot of the graph, viz. 94 lb. approximately.

(3) STRESSES ON ANGLE AND TERMINAL POLES, AND INSULATOR SPINDLES, OF HIGH-VOLTAGE LINES.

From Figs. 3A to 3G, the transverse load (excluding windage) on a pole due to the deviation of a line can be read directly for most classes of conductors on high-voltage lines for any angle of deviation up to 120°. The stress on a terminal pole will be the same as on a 60° angle pole. A curve showing the value of the sine of the angle which the stay makes with the pole is also included in each graph. If the value of the transverse load on the pole is divided by the sine of the angle which the stay makes with the pole, the tension in the actual stay wire is obtained.

Example (i).

To find the stress near the pole top due to a deviation of 40° on a 3-wire high-voltage route consisting of three 0·1-sq. in. hard-drawn copper conductors, and also the tension in the stay, if this has a spread of 45°. On the left-hand vertical scale of Fig. 3A read 40°, and follow along horizontally to the right until the 0·1-sq. in. graph

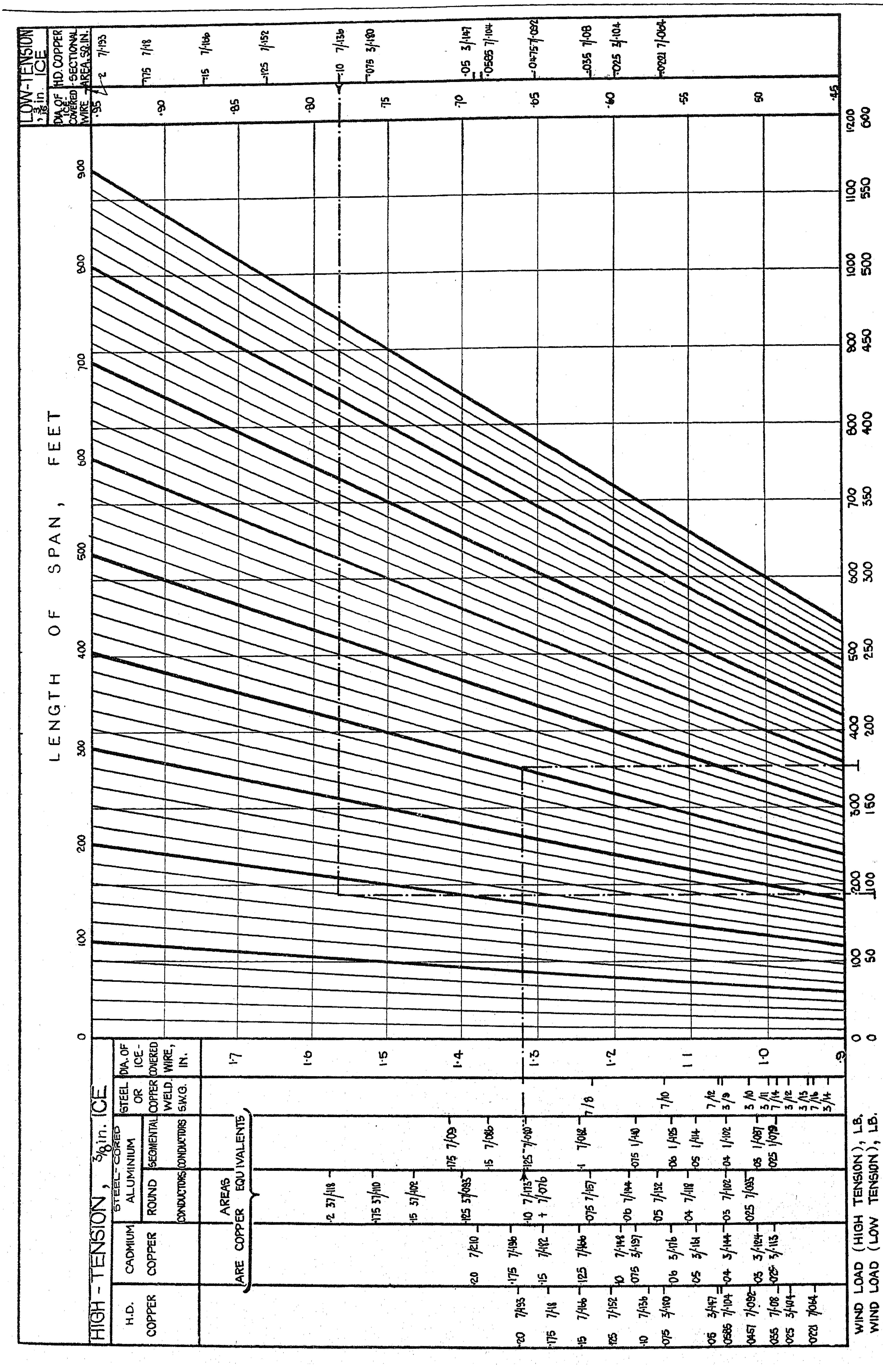

FIG. 2.—Wind load on ice-covered wires.
Wind pressure = 8 lb. per sq. ft. of projected area.

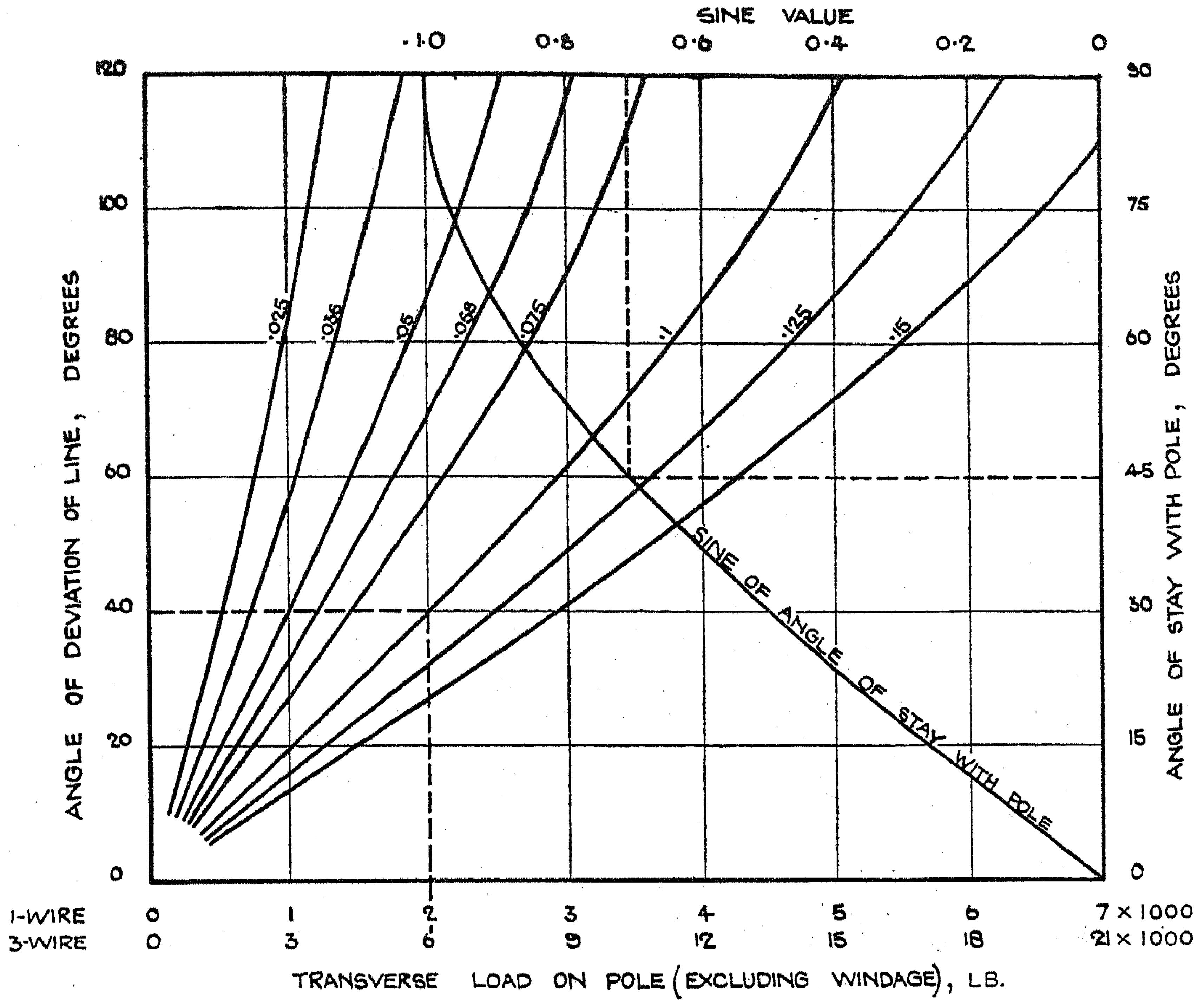

FIG. 3A.—Hard-drawn copper.

Factor of safety = 2·0. Thickness of ice-covering = $\frac{3}{8}$ in. Wind pressure = 8 lb. per sq. ft. of projected area.

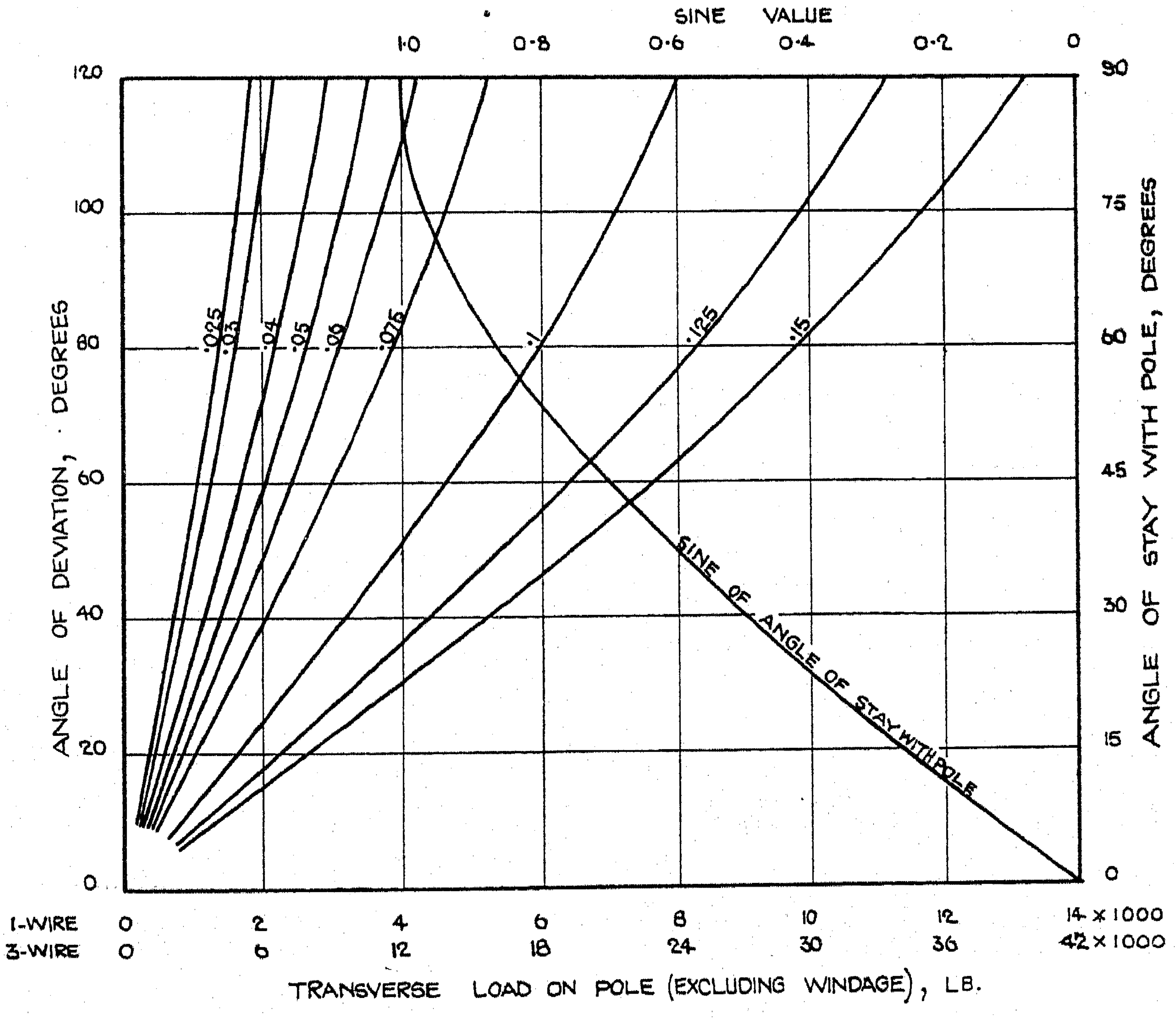

FIG. 3B.—Steel-cored aluminium (round stranded).

Factor of safety = 2·0. Thickness of ice-covering = $\frac{3}{8}$ in. Wind pressure = 8 lb. per sq. ft. of projected area.

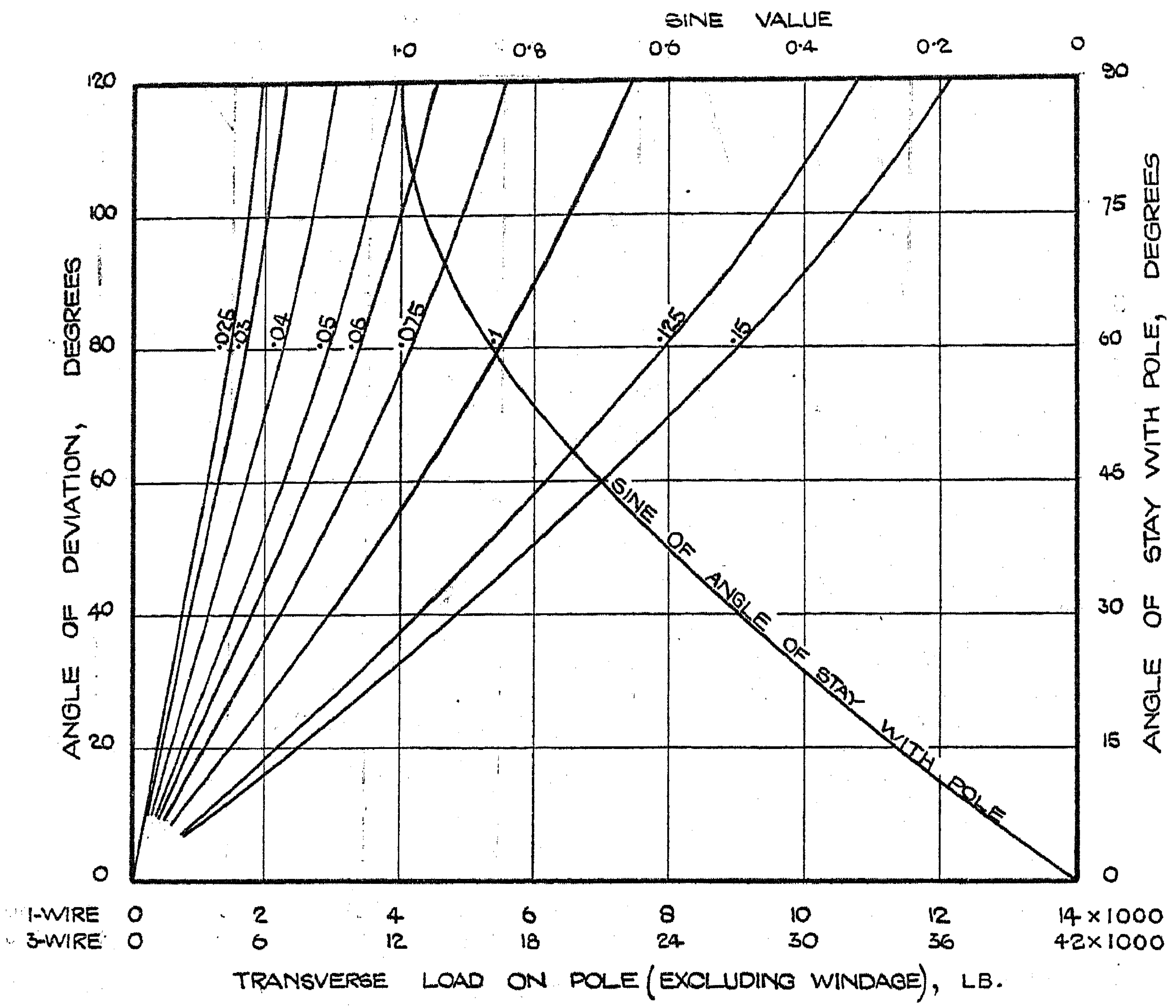

FIG. 3C.—Steel-cored aluminium (segmental).

Factor of safety = 2·0. Thickness of ice-covering = ⅜ in. Wind pressure = 8 lb. per sq. ft. of projected area.

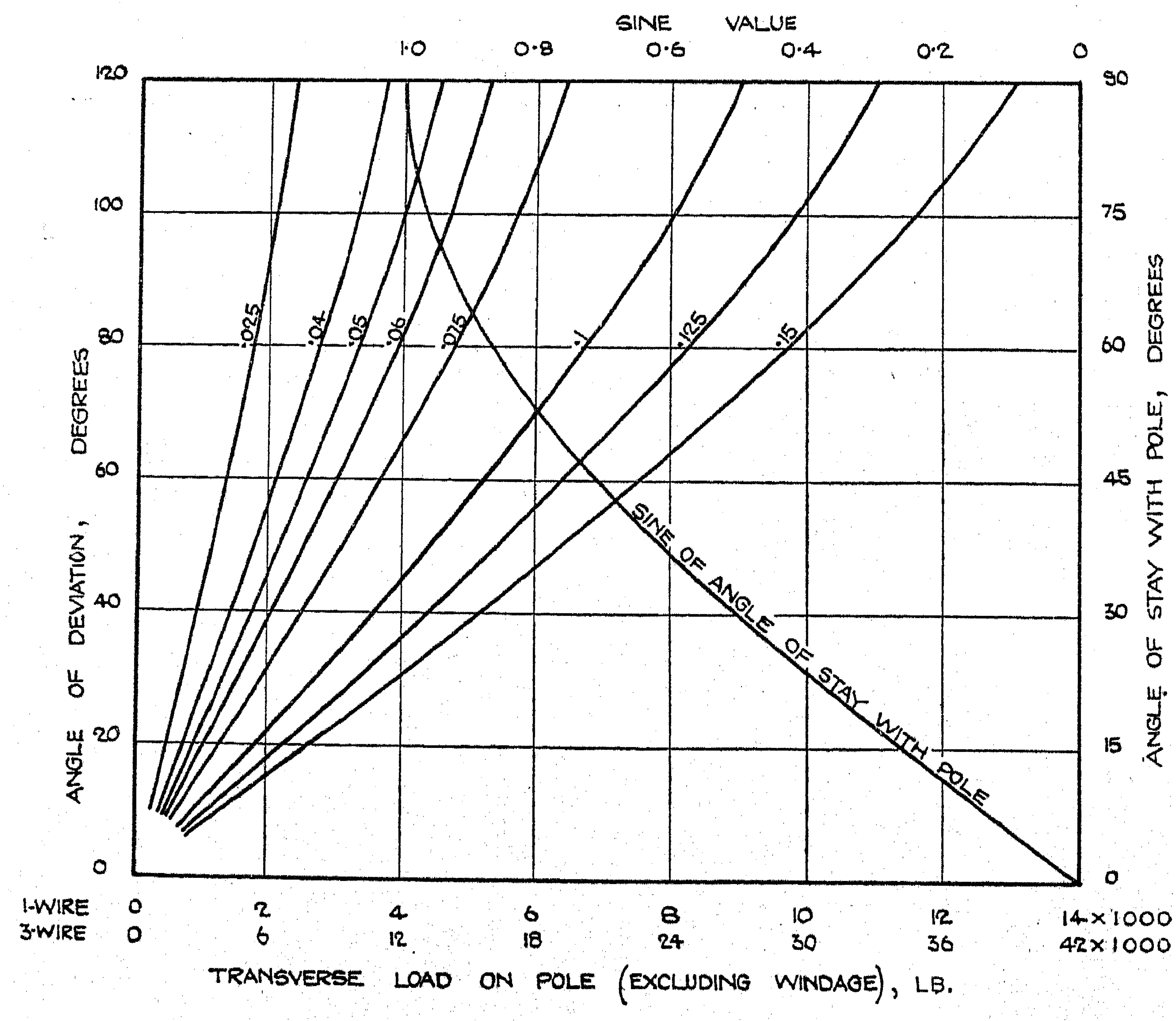

FIG. 3D.—Cadmium copper, 84 per cent conductivity.

Factor of safety = 2·0. Thickness of ice-covering = ⅜ in. Wind pressure = 8 lb. per sq. ft. of projected area.

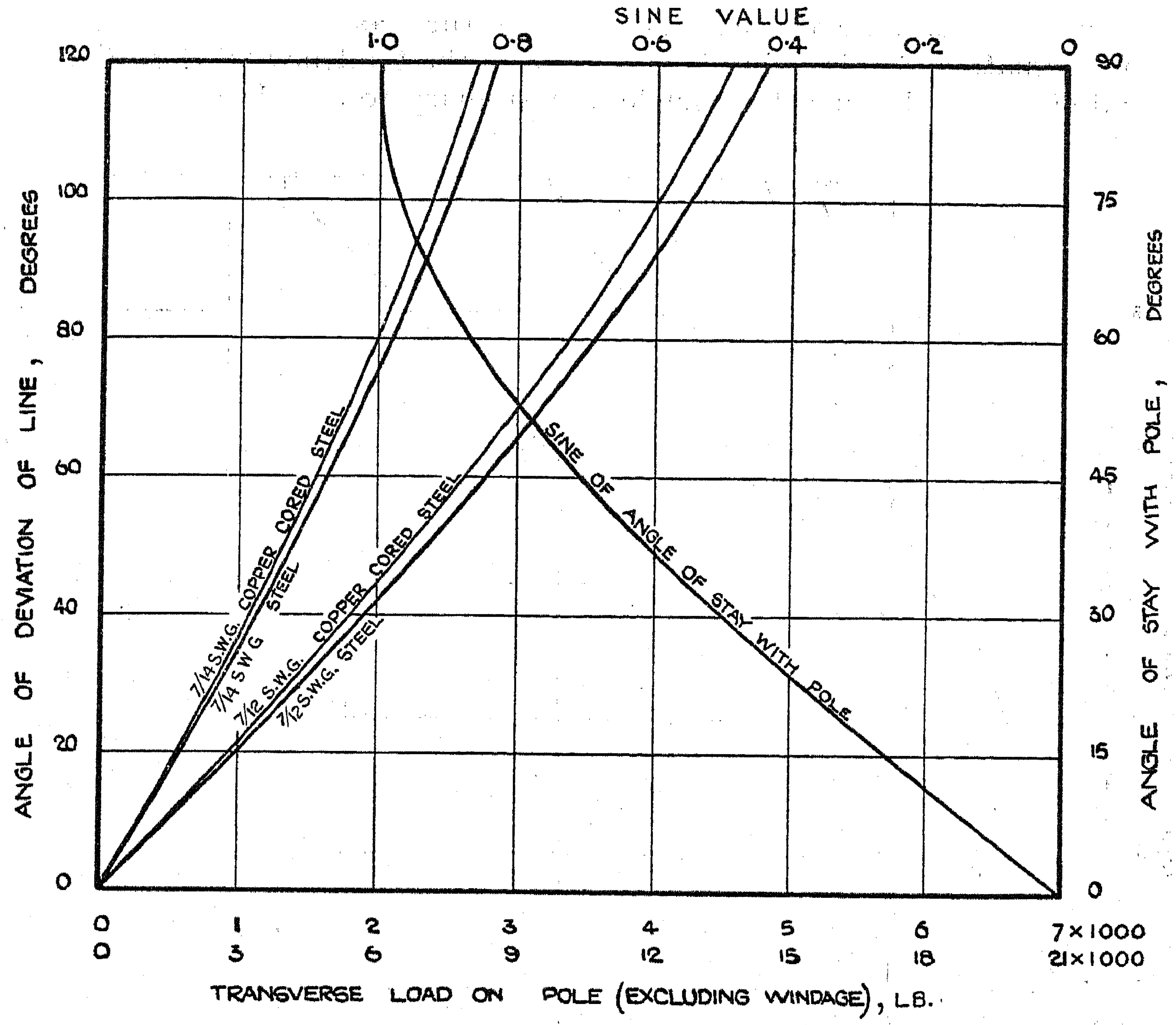

FIG. 3E.—Steel conductors and copper-cored steel conductors.

Factor of safety = 2·0. Thickness of ice-covering = $\frac{3}{8}$ in. Wind pressure = 8 lb. per sq. ft. of projected area.

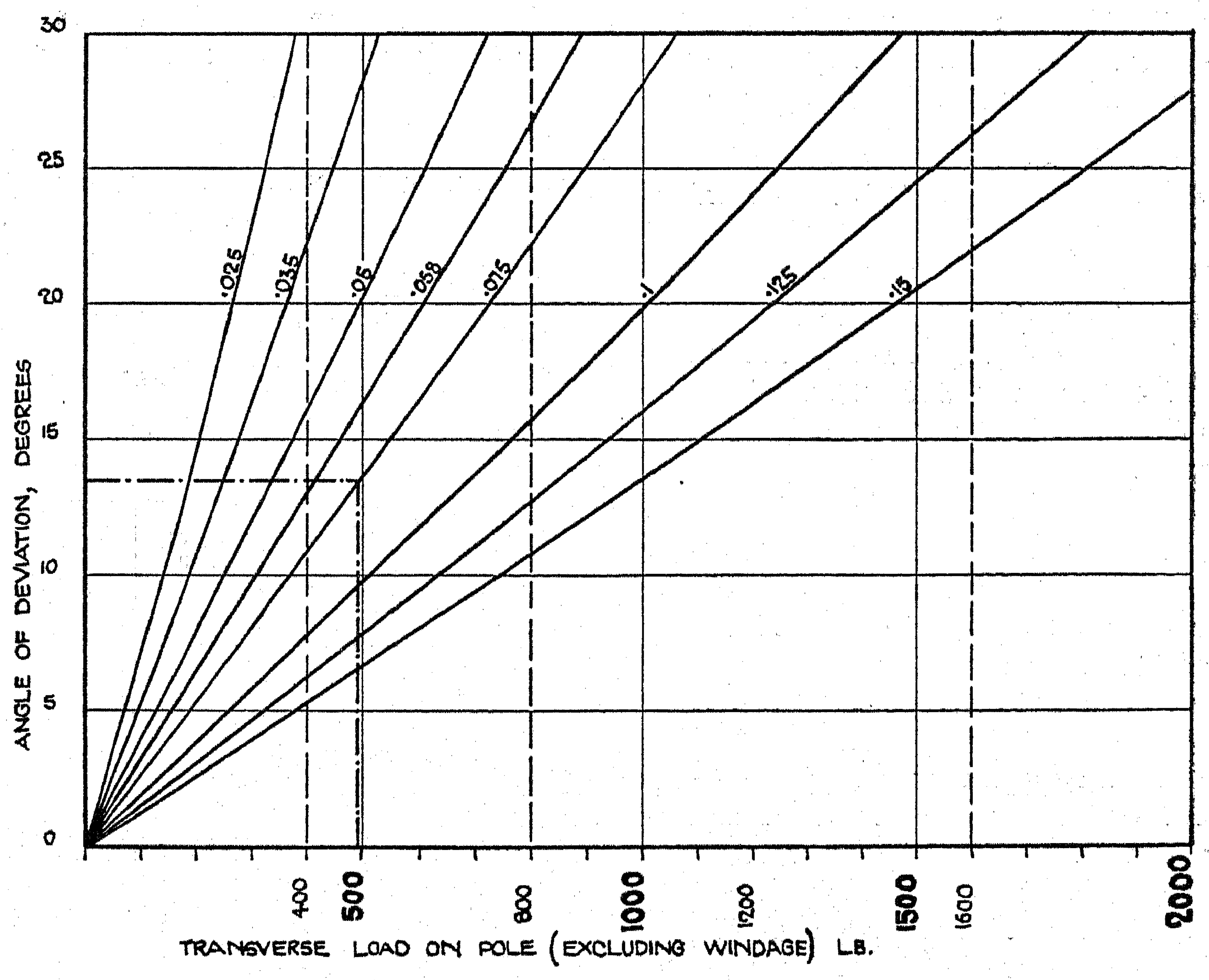

FIG. 3F.—Hard-drawn copper.

Factor of safety = 2·0. Thickness of ice-covering = $\frac{3}{8}$ in. Wind pressure = 8 lb. per sq. ft. of projected area.

is reached. Immediately below the point of intersection read off the stress value on the lower scale at the foot of graph, viz. 6 020 lb. approximately. This value is the stress near the pole top: dividing by the sine of the angle between the stay and the pole gives the stress in the stay. On the right-hand vertical scale read 45°, and follow along horizontally to the left to the point of intersection with the graph of sine values. Immediately above this point read off on the top horizontal scale the value 0·707. Then

$$\text{Stress in stay wire} = \frac{6\,020}{0 \cdot 707} = 8\,515 \text{ lb. (approx.)}$$

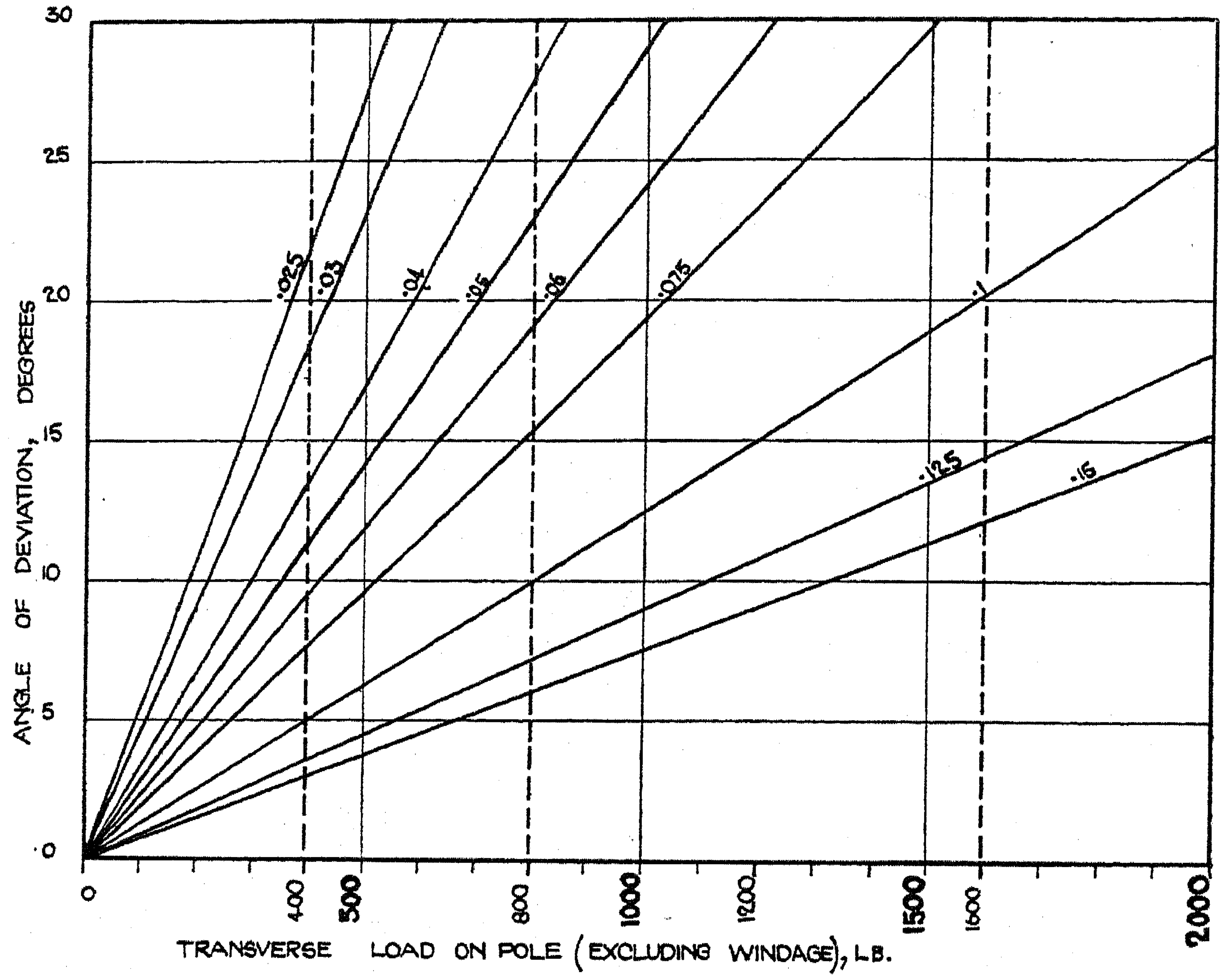

FIG. 3G.—Steel-cored aluminium (round stranded).

Factor of safety = 2·0. Thickness of ice-covering = $\frac{3}{8}$ in. Wind pressure = 8 lb. per sq. ft. of projected area.

By enlarging the graphs as shown in Figs. 3F and 3G and using these graphs in conjunction with Fig. 2, the maximum angles which may be negotiated on standard insulator spindles of 400 lb. and 800 lb. safe load (or 1 600 lb. where two 800-lb. spindles are used in parallel) can be read off directly.

Example (ii).

To find the maximum angle of deviation which may be made on a single 800-lb. spindle on a 0·075-sq. in. hard-drawn copper line of 400-ft. spans: First determine from Fig. 2 the wind load on a 400-ft. span of 0·075-sq. in. hard-drawn copper conductor with a $\frac{3}{8}$-in. radial thickness of ice, viz. 304 lb. approximately. Deduct this amount from 800 lb., obtaining 496 lb. Read off 496 on the bottom horizontal scale of Fig. 3F, and follow along the vertical line above to the point of intersection with the graph for 0·075 sq. in. conductor. Follow from this point of intersection the horizontal to the left, and read off the maximum angle of deviation for the 800-lb. spindle on a 400-ft. span (= $13\frac{1}{2}$° approximately).

Copperweld Conductors.

In the case of copperweld conductors, in order to avoid the tendency to vibration and crystallization, it is customary to calculate the sags and stresses so that the maximum tension at 60° F. allows a factor of safety of 5. Thus the maximum tension under worst conditions varies according to the span length involved, and it is not practicable to prepare a similar graph for this class of conductor which would be applicable to all span lengths.

(4) STRESSES ON ANGLE AND TERMINAL STAYS OF LOW-VOLTAGE ROUTES.

As a result of the large number of angle and terminal poles usually necessary on low-voltage distribution schemes in typical rural areas, and the comparatively heavy section of the conductors involved, it is impracticable to strain the conductors up to the limits allowable

TABLE 1.

Cross-sectional area	Maximum tension under worst conditions		
	Basis: a sag of 3 ft. 6 in. on 180-ft. spans at 122° F.	Basis: a sag of 3 ft. on 180-ft. spans at 122° F.	Basis: El.C. 53
sq. in.	lb.	lb.	lb.
0·1	1 221	1 484	2 936
0·0585	845	989	1 771
0·0221	477·5	527	686

TABLE 2.

Stresses on Angle and Terminal Stays of Low-voltage Lines, Based on Maximum Span of 180 ft. and Sag of 3 ft. on 180-ft Span at 122° F.

Angle of deviation of route	Angle of stay with pole	0·1-sq. in. routes				0·0585-sq. in. routes			
		4 × 0·1 + 0·0221	4 × 0·1	3 × 0·1	2 × 0·1	4 × 0·0585 + 0·0221	4 × 0·0585	3 × 0·0585	2 × 0·0585
deg.	deg.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
10	15	6 053	5 436	4 077	2 718	4 541	3 924	2 943	1 962
	30	3 136	2 816	2 112	1 408	2 356	2 036	1 527	1 018
	45	2 213	1 988	1 491	994	1 665	1 440	1 080	720
	60	1 808	1 624	1 218	812	1 350	1 176	882	588
20	15	10 399	9 428	7 071	4 714	7 547	6 576	4 932	3 288
	30	5 383	4 880	3 660	2 440	3 907	3 404	2 553	1 702
	45	3 803	3 448	2 586	1 724	2 759	2 404	1 803	1 202
	60	3 106	2 816	2 112	1 408	2 256	1 966	1 474	983
30	15	14 625	13 308	9 981	6 654	10 481	9 164	6 873	4 582
	30	7 578	6 896	5 172	3 448	5 438	4 756	3 567	2 378
	45	5 358	4 876	3 657	2 438	3 842	3 360	2 520	1 680
	60	4 374	3 980	2 985	1 990	3 138	2 744	2 058	1 372
45	15	20 767	18 948	14 211	9 474	14 747	12 928	9 696	6 464
	30	10 751	9 808	7 356	4 904	7 651	6 708	5 031	3 354
	45	7 602	6 936	5 202	3 468	5 402	4 736	3 552	2 368
	60	6 208	5 664	4 248	2 832	4 416	3 872	2 904	1 936
60	15	26 660	24 360	18 270	12 180	18 560	16 560	12 420	8 280
	30	13 814	12 624	9 468	6 312	9 762	8 572	6 429	4 286
	45	9 761	8 920	6 690	4 460	6 901	6 060	4 545	3 030
	60	7 971	7 284	5 463	3 642	5 631	4 940	3 708	2 472
90	15	36 973	33 832	25 374	16 916	25 981	22 840	17 130	11 420
	30	19 148	17 520	13 140	8 760	13 456	11 828	8 871	5 914
	45	13 534	12 384	9 288	6 192	9 510	8 360	6 270	4 180
	60	11 052	10 112	7 584	5 056	7 764	6 824	5 118	3 412
120	15	44 907	41 120	30 840	20 560	31 443	27 656	20 742	13 828
	30	23 258	21 296	15 972	10 648	16 278	14 316	10 587	7 158
	45	16 438	15 052	11 289	7 526	11 506	10 120	7 590	5 060
	60	13 423	12 292	9 219	6 146	9 395	8 264	6 198	4 132
Terminal	15	24 944	22 908	17 181	11 454	17 316	15 280	11 460	7 640
	30	12 926	11 872	8 904	5 936	8 966	7 912	5 934	3 956
	45	9 138	8 392	6 294	4 196	6 330	5 584	4 188	2 792
	60	7 460	6 852	5 139	3 426	5 172	4 564	3 423	2 282

under the Electricity Commissioners' Regulations El.C. 53 for low-voltage lines, owing to the excessive stress which would thereby be imposed on stays, struts, poles, and fittings. The author suggests, as a good practical value for average conditions, a tension which provides a sag of 3 ft. on spans of 180 ft. at 122° F. An alternative suggestion for schemes where the angles are numerous, is a tension to give a sag of 3 ft. 6 in. on 180-ft. spans at 122° F.

Table 1 gives details of the maximum tensions experienced under worst conditions ($\frac{3}{16}$-in. radial ice coating, 8 lb. per sq. in. wind, and a temperature of 22° F.) with conductors having cross-sectional areas of 0·1 sq. in., 0·0585 sq. in., and 0·0221 sq. in. respectively.

Tables 2 and 3 have been prepared for the two different basic conditions, and show the stresses in angle and terminal stays for 0·1-sq. in. and 0·0585-sq. in. low-voltage routes, covering angles of deviation from 10° to 120°, terminals, and stays having a spread of 15° to 60° with the pole. These tables should be used in conjunction with the sags and tensions given in Tables 7L and 7M respectively.

TABLE 3.

Stresses on Angle and Terminal Stays of Low-voltage Lines, Based on Maximum Span of 180 ft. and Sag of 3 ft. 6 in. on 180-ft. Span at 122° F.

Angle of deviation of route	Angle of stay with pole	0·1-sq. in. routes				0·0585-sq. in. routes			
		4 × 0·1 + 0·0221	4 × 0·1	3 × 0·1	2 × 0·1	4 × 0·0585 + 0·0221	4 × 0·0585	3 × 0·0585	2 × 0·0585
deg.	deg.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
10	15	5 323	4 740	3 555	2 370	4 127	3 544	2 658	1 772
	30	2 758	2 456	1 842	1 228	2 138	1 836	1 377	918
	45	1 945	1 732	1 299	866	1 511	1 298	973	649
	60	1 590	1 416	1 062	708	1 234	1 060	795	530
20	15	8 902	8 000	6 000	4 000	6 702	5 800	4 350	2 900
	30	4 611	4 144	3 108	2 072	3 471	3 004	2 253	1 502
	45	3 262	2 932	2 199	1 466	2 456	2 126	1 594	1 063
	60	2 665	2 396	1 797	1 198	2 005	1 736	1 302	868
30	15	12 415	11 200	8 400	5 600	9 243	8 028	6 021	4 014
	30	6 437	5 808	4 356	2 904	4 789	4 160	3 120	2 080
	45	4 552	4 108	3 081	2 054	3 384	2 940	2 205	1 470
	60	3 715	3 352	2 514	1 676	2 763	2 400	1 800	1 200
45	15	17 541	15 868	11 901	7 934	12 913	11 240	8 430	5 620
	30	9 083	8 216	6 162	4 108	6 695	5 828	4 371	2 914
	45	6 425	5 812	4 359	2 906	4 733	4 120	3 090	2 060
	60	5 244	4 744	3 558	2 372	3 864	3 364	2 523	1 682
60	15	22 428	20 324	15 243	10 162	16 424	14 320	10 740	7 160
	30	11 611	10 520	7 890	5 260	8 511	7 420	5 565	3 710
	45	8 211	7 440	5 580	3 720	6 015	5 244	3 933	2 622
	60	6 701	6 072	4 554	3 036	4 913	4 284	3 213	2 142
90	15	30 993	28 128	21 096	14 064	22 577	19 712	14 784	9 856
	30	16 044	14 560	10 920	7 280	11 704	10 220	7 665	5 110
	45	11 345	10 296	7 722	5 148	8 285	7 236	5 427	3 618
	60	9 260	8 404	6 303	4 202	6 756	5 900	4 425	2 950
120	15	37 574	34 124	25 593	17 062	27 360	23 912	17 934	11 956
	30	19 452	17 664	13 248	8 832	14 168	12 380	9 852	6 190
	45	13 755	12 492	9 369	6 246	10 019	8 756	6 567	4 378
	60	11 228	10 196	7 647	5 098	8 180	7 148	5 361	3 574
Terminal	15	20 716	18 872	14 154	9 436	14 888	13 044	9 783	6 522
	30	10 723	9 768	7 326	4 884	7 715	6 760	5 070	3 380
	45	7 582	6 908	5 181	3 454	5 438	4 764	3 573	2 382
	60	6 191	5 640	4 230	2 820	4 451	3 900	2 925	1 950

(5) DETAILS OF STAY BLOCKS, WIRE, AND RODS.

Tables 4 and 5 are self-explanatory, and Table 6 has been included for the sake of completeness while dealing with stays.

Assuming a factor of safety of 2·5, the safe working loads for galvanized-steel stay rods are as follows: ⅝-in. diameter, 4 260 lb. per sq. in.; ¾-in., 6 360 lb. per sq. in.; ⅞-in., 8 760 lb. per sq. in.; 1-in., 11 640 lb. per sq. in.

(6) SAG AND STRESS TABLES FOR VARIOUS CLASSES OF CONDUCTORS.

High-Voltage Lines.

The sags and stresses given in Tables 7A to 7H are based on the Electricity Commissioners' Regulations El.C. 53 for high-voltage lines, with the exception of those for copperweld conductors, which are calculated so that the tension at 60° F. does not exceed one-fifth of the breaking stress, for the reason already referred to.

TABLE 4.

Approximate Depth in Ground (ft.) to Top Face of Stay Block, assuming 2 *ft. of Rod above Ground and Blocks of* 10 *in.* × 5 *in. cross-section.*

Angle of stay with pole =	15°	30°	45°	60°
6-ft. stay rod	3·5	3·1	2·5	1·8
8-ft. stay rod	5·4	4·9	4	2·8
9-ft. stay rod	6·4	5·7	4·6	3·3

Low-Voltage Lines.

Tables 7J and 7K give the sags and stresses for solid and stranded hard-drawn copper conductors based on the above Regulations El.C. 53 for low-voltage lines.

These tables are based on a factor of safety of 2 for the conductors, under the specified "worst conditions," but, as previously explained in Section (4), such stresses are generally impracticable when using the heavier conductors usually associated with low- and medium-voltage overhead distribution lines. Tables 7L and 7M, relating to three popular sizes of stranded hard-drawn copper conductors, are based on considerably lower conductor stresses which have been found useful in practice. In Table 7L the basis is a sag of 3 ft., and in Table 7M of 3 ft. 6 in., on 180-ft. spans at 122° F. Both have proved useful practical values.

TABLE 6.

Weights, Diameters, and Safe Working Loads, for Galvanized-steel Wires and Stranded Cables, assuming a Factor of Safety of 2·5.

Conductor size	Diameter	Approx. weight per 1 000 ft.	Safe working load		
			25-ton quality	45-ton quality	60-ton quality
S.W.G.	in.	lb.	lb.	lb.	lb.
4	0·232	144	946	1 704	2 272
5	0·212	120	790	1 423	1 897
6	0·192	98	648	1 167	1 556
7	0·176	83	545	981	1 308
8	0·16	68	450	810	1 081
9	0·144	55	365	657	875
10	0·128	44	288	518	691
3/8	0·345	210	1 242	2 237	2 983
4/8	0·387	279	1 657	2 982	3 977
5/8	0·413	348	2 071	3 728	4 971
7/18	0·144	44	270	484	646
7/17	0·168	60	366	660	880
7/16	0·192	78	479	860	1 148
7/15	0·216	99	606	1 088	1 452
7/14	0·24	122	749	1 344	1 796
7/13	0·276	162	990	1 780	2 376
7/12	0·312	207	1 264	2 276	3 036
7/11	0·348	258	1 572	2 832	3 776
7/10	0·384	315	1 916	3 448	4 596
7/9	0·432	398	2 424	4 364	5 820
7/8	0·48	492	2 992	5 388	7 188
7/7	0·528	595	3 475	6 255	8 340
7/6	0·576	700	4 175	7 514	10 019
19/14	0·4	337	1 968	3 540	4 720
19/12	0·52	571	3 328	5 988	7 984
19/10	0·64	865	5 036	9 064	12 088
19/8	0·8	1 350	7 872	14 168	18 892

TABLE 5.—*Safe Load for Stay Blocks in Well-drained Loamy Soil, assuming* 2 *ft. of Stay Rod above Ground.*

Size of stay block*	Area	Length of stay rod	Angle of stay with pole			
			15°	30°	45°	60°
	sq. ft.	ft.				
3 ft. × 8 in. × 4 in.	2	6	2 040	1 900	1 550	1 020
		8	4 860	4 740	3 960	2 440
		9	6 840	6 420	5 240	3 400
3 ft. × 10 in. × 5 in.	2½	6	2 550	2 375	1 937	1 275
		8	6 075	5 925	4 950	3 050
		9	8 550	8 025	6 550	4 250
4½ ft. × 8 in. × 4 in.	3	6	3 060	2 850	2 325	1 530
		8	7 290	7 110	5 940	3 660
		9	10 260	9 630	7 860	5 100
4½ ft. × 10 in. × 5 in.	3¾	6	3 825	3 560	2 905	1 910
		8	9 110	8 890	7 425	4 575
		9	12 850	12 040	9 825	6 375
6 ft. × 10 in. × 5 in.	5	6	5 100	4 750	3 875	2 550
		8	12 150	11 850	9 900	6 100
		9	17 100	16 050	13 100	8 500

* It is obvious that for stays having a big spread, e.g. 60° with the pole, the block must be large in size, owing to the small depth of the hole, even when long stay-rods are used.

TABLE 7A.

Erection Sags and Tensions for Hard-Drawn Stranded Copper Conductors with ⅜-in. Radial Ice Covering and 8 lb. per sq. ft. Wind Pressure on Projected Area. Factor of Safety = 2.

Particulars of strand*	Temperature	180-ft. span		240-ft. span		300-ft. span		360-ft. span		400-ft. span		450-ft. span		500-ft span	
		Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip
	° F.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.
(a) 0·025 sq. in.	22 (ice)	759	4·02	759	7·14	759	11·15								
(b) 3/·104″	22 (no ice)	250	1·59	154	4·60	128	8·78								
(c) 0·224 in.	40	218	1·87	145	5·02	124	9·1								
(d) 64·93 lb.	60	185	2·2	135	5·35	120	9·4								
(e) 300·6 lb.	80	160	2·54	128	5·66	116	9·72								
(f) 0·9887 ohm	122	127	3·2	114	6·32	109	10·35								
(a) 0·035 sq. in.	22 (ice)	1 062	2·99	1 062	5·32	1 062	8·32	1 062	11·97	1 062	14·78				
(b) 7/·08″	22 (no ice)	642	0·87	413	2·41	296	5·25	250	8·95	234	11·79				
(c) 0·24 in.	40	551	1·01	360	2·76	274	5·67	239	9·36	227	12·15				
(d) 66·0 lb.	60	458	1·22	314	3·16	254	6·12	229	9·76	219	12·6				
(e) 413·8 lb.	80	378	1·48	278	3·57	238	6·52	219	10·2	212	13·0				
(f) 0·7143 ohm	122	259	2·16	225	4·42	210	7·4	203	11·04	200	13·83				
(a) 0·05 sq. in.	22 (ice)	1 457	2·45	1 457	4·36	1 457	6·82	1 457	9·82	1 457	12·11	1 457	15·34		
(b) 3/·147″	22 (no ice)	1 055	0·77	800	1 8	598	3·77	489	6·63	448	8·94	417	12·15		
(c) 0·317 in.	40	919	0·88	695	2 07	538	4·19	459	7·09	426	9 ·4	402	12·6		
(d) 71·13 lb.	60	777	1·04	594	2 43	483	4·66	427	7·6	405	9·89	387	13·1		
(e) 600·5 lb.	80	646	1·25	513	2 81	439	5·13	401	8·09	386	10·37	373	13·6		
(f) 0·4943 ohm	122	436	1·86	393	3·67	371	6·07	358	9·06	353	11·34	348	14·55		
(a) 0·058 sq. in.	22 (ice)	1 771	2·05	1 771	3·65	1 771	5·71	1 771	8·22	1 771	10·14	1 771	12·84		
(b) 7/·104″	22 (no ice)	1 442	0·65	1 214	1·38	979	2·68	795	4·75	713	6·54	645	9·15		
(c) 0·312 in.	40	1 274	0·74	1 063	1·58	864	3·04	721	5·24	660	7·06	608	9·71		
(d) 70·8 lb.	60	1 091	0·87	909	1·85	754	3·48	653	5·78	610	7·64	573	10·3		
(e) 699·3 lb.	80	919	1·03	773	2·17	664	3·95	597	6·32	568	8·21	543	10·86		
(f) 0·4225 ohm	122	614	1·54	561	2·99	528	4·97	508	7·43	499	9·34	491	12·0		
(a) 0·075 sq. in.	22 (ice)	2 125	1·912	1 225	3·4	2 125	5·31	2 125	7·65	2 125	9·44	2 125	11·95		
(b) 3/·180″	22 (no ice)	1 772	0·69	1 529	1·41	1 278	2·64	1 073	4·53	975	6·16	889	8·55		
(c) 0·388 in.	40	1 563	0·78	1 342	1·61	1 131	2·99	972	5·0	900	6·67	836	9·1		
(d) 75·86 lb.	60	1 339	0·91	1 151	1·88	990	3·41	879	5·53	829	7·24	785	9·68		
(e) 900·3 lb.	80	1 127	1·08	984	2·2	874	3·88	802	6·06	769	7·81	740	10·26		
(f) 0·3294 ohm	122	760	1·6	721	3·0	695	4·86	679	7·16	672	8·93	665	11·42		
(a) 0·1 sq. in.	22 (ice)	2 936	1·5	2 936	2·67	2 936	4·17	2 936	6·0	2 936	7·4	2 936	9·375		
(b) 7/·136″	22 (no ice)	2 658	0·61	2 459	1·17	2 228	2·01	1 994	3·24	1 851	4·41	1 697	5·95		
(c) 0·408 in.	40	2 373	0·68	2 189	1·32	1 986	2·26	1 790	3·61	1 675	4·76	1 556	6·48		
(d) 77·2 lb.	60	2 063	0·78	1 903	1·51	1 737	2·58	1 588	4·07	1 505	5·3	1 421	7·1		
(e) 1 196 lb.	80	1 764	0·92	1 638	1·75	1 516	2·96	1 415	4·56	1 360	5·86	1 307	7·72		
(f) 0·2469 ohm	122	1 208	1·34	1 179	2·44	1 155	3·88	1 138	5·66	1 129	7·06	1 120	9·02		
(a) 0·125 sq. in.	22 (ice)	3 616	1·341	3 616	2·39	3 616	3·73	3 616	5·37	3 616	6·63	3 616	8·39	3 616	10·35
(b) 7/·152″	22 (no ice)	3 351	0·60	3 160	1·14	2 936	1·91	2 700	2·99	2 548	3·91	2 375	5·31	2 226	7·0
(c) 0·456 in.	40	2 994	0·67	2 820	1·27	2 624	2·14	2 425	3·33	2 303	4·33	2 168	5·82	2 056	7·58
(d) 80·4 lb.	60	2 606	0·78	2 459	1·46	2 300	2·44	2 150	3·76	2 062	4·83	1 968	6·41	1 890	8·24
(e) 1 494 lb.	80	2 232	0·90	2 120	1·69	2 009	2·79	1 910	4·23	1 854	5·375	1 796	7·02	1 749	8·91
(f) 0·1993 ohm	122	1 530	1·32	1·525	2·35	1 522	3·68	1 519	5·32	1 516	6·67	1 515	8·33	1 514	10·28
(a) 0·15 sq. in.	22 (ice)	4 263	1·24	4 263	2·2	4 263	3·44	4 263	4·95	4 263	6·12	4 263	7·74	4 263	9·56
(b) 7/·166″	22 (no ice)	4 005	0·60	3 819	1·12	3 600	1·86	3 364	2·86	3 209	3·70	3 025	4·97	2 861	6·49
(c) 0·498 in.	40	3 577	0·67	3 410	1·25	3 220	2·08	3 023	3·19	2 899	4·10	2 756	5·46	2 632	7·06
(d) 83·2 lb.	60	3 111	0·77	2 974	1·44	2 824	2·37	2 679	3·60	2 590	4·59	2 492	6·03	2 410	7·7
(e) 1 782 lb.	80	2 661	0·90	2 564	1·67	2 465	2·71	2 375	4·06	2 322	5·12	2 265	6·64	2 218	8·37
(f) 0·1656 ohm	122	1 821	1·32	1 842	2·32	1 860	3·60	1 875	5·14	1 884	6·31	1 893	7·94	1 900	9·77

* (a) = Actual cross-sectional area, sq. in. (b) = Number and diameter (in.) of strands. (c) = Overall diameter, in. (d) = Wind pressure (lb.) per 100 ft. (e) = Approximate weight (lb.) per 1 000 yards. (f) = Approximate resistance (ohms) per 1 000 yards at 60° F.

TABLE 7B.

Erection Sags and Tensions for Steel-Cored Aluminium (Round) Stranded Conductors with ⅜-in. Radial Ice Covering and 8 lb. per sq. ft. Wind Pressure on Projected Area. Factor of Safety = 2. Breaking Stress of Conductor = 2 × Tension at 22° F. with Wind and Ice.

Particulars of strand*	Temperature	180-ft. span		240-ft. span		300-ft. span		360-ft. span		400-ft. span		450-ft. span		500-ft. span	
		Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip
	°F.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.
(a) 0·025 sq. in.	22 (ice)	1 080	2·93	1 080	5·22	1 080	8·15	1 080	11·74	1 080	14·5	1 080	18·34		
(b) 6/·093″ + 1/·093″	22 (no ice)	675	0·43	390	1·32	203	3·98	149·5	7·78	135	10·64	124·7	14·58		
(c) 0·280 in.	40	568	0·51	308	1·68	177·2	4·56	140	8·31	129·4	11·10	120·8	15·05		
(d) 68·06 lb.	60	451	0·64	237	2·18	156·3	5·17	131·3	8·86	123·1	11·66	116·8	15·56		
(e) 215 lb.	80	342	0·85	187·5	2·76	140·6	5·74	123·7	9·41	118	12·17	113·2	16·06		
(f) 0·991 ohm	122	177	1·64	133	3·89	118·1	5·84	111·5	10·42	108·9	13·19	106·7	17·04		
(a) 0·03 sq. in.	22 (ice)	1 272	2·58	1 272	4·59	1 272	7·17	1 272	10·32	1 272	12·74	1 272	16·13		
(b) 6/·102″ + 1/·102″	22 (no ice)	896	0·39	620	1·00	356·5	2·72	236·1	5·93	204·2	8·46	183·1	11·94		
(c) 0·306 in.	40	765	0·46	503	1·22	294·6	3·30	214	6·54	191	9·06	175	12·49		
(d) 70·4 lb.	60	623	0·56	388·5	1·58	245·7	3·95	194·5	7·20	178·8	9·67	167	13·09		
(e) 259 lb.	80	487	0·72	298·5	2·05	211·5	4·59	17·92	7 82	168·4	10·26	160·2	13·65		
(f) 0·824 ohm	122	255	1·37	109·9	3·26	166·7	5·83	155·6	9·00	151·4	11·42	147·8	14·8		
(a) 0·04 sq. in.	22 (ice)	1 705	2·05	1 705	3·65	1 705	5·71	1 705	8·23	1 705	10·15	1 705	12·85	1 705	15·87
(b) 6/·118″ + 1/·118″	22 (no ice)	1 385	0·34	1 147	0·72	856·5	1·52	587·5	3·19	467·5	4·95	382	7·66	336·3	10·75
(c) 0·354 in.	40	1 209	0·39	977	0·85	708	1·84	492·5	3·8	408·4	5·66	349	8·39	315·5	11·45
(d) 73·64 lb.	60	1 015	0·46	796	1·04	563	2·31	415	4·54	359	6·44	319·1	9·17	296	12·21
(e) 347 lb.	80	824	0·57	628	1·32	449	2·90	357·3	4·99	321·1	7·21	295·2	9·92	279·7	12·93
(f) 0·615 ohm	122	462	1·01	868·5	2·26	305·2	4·28	278	6·74	267·4	8·65	258	11·34	252	14·35
(a) 0·05 sq. in.	22 (ice)	2 052	1·80	2 052	3·21	2 052	5·01	2 052	7·22	2 052	8·91	2 052	11·27	2 052	13·92
(b) 6/·132″ + 1/·132″	22 (no ice)	1 748	0·33	1 517	0·69	1 234	1·32	939	2·5	770	3·76	619·6	5·92	530	8·54
(c) 0·396 in.	40	1 527	0·38	1 302	0·80	1 036	1·57	782	3·00	653·5	4·44	548	6·69	485	9·33
(d) 76·45 lb.	60	1 285	0·46	1 070	0·97	835	1·95	641	3·66	355·5	5·22	486·5	7·54	445	10·15
(e) 434 lb.	80	1 047	0·56	852	1·22	663·5	2·46	534·5	4·39	482	6·01	439	8·16	412	10·98
(f) 0·492 ohm	122	590	0·99	493	2·11	431	3·78	396	5·93	382	7·59	369	9·94	360	12·55
(a) 0·06 sq. in.	22 (ice)	2 442	1·59	2 442	2·83	2 442	4·42	2 442	6·37	2 442	7·87	2 442	9·96	2 442	12·28
(b) 6/·144″ + 1/·144″	22 (no ice)	2 162	0·32	1 949	0·64	1 685	1·15	1 389	2·01	1 193	2·89	980	4·45	823·5	6·52
(c) 0·432 in.	40	1 898	0·37	1 690	0·71	1 437	1·35	1 169	2·39	1 005	3·43	842	5·18	730	7·37
(d) 78·90 lb.	60	1 607	0·43	1 408	0·88	1 177	1·64	955	2·92	834	4·13	722·5	6·03	649	8·30
(e) 516 lb.	80	1 319	0·53	1 137	1·09	942	2·06	780	3·58	701	4·92	632	6·90	585·4	9·20
(f) 0·413 ohm	122	759	0·92	662	1·87	590	3·29	544·3	5·13	523·5	6·58	505	8·64	491·1	10·96
(a) 0·075 sq. in.	22 (ice)			3 017	2·45	3 017	3·84	3 017	5·52	3 017	6·82	3 017	8·64	3 017	10·65
(b) 6/·161″ + 1/·161″	22 (no ice)			2 561	0·60	2 314	1·05	2 028	1·72	1 827	2·35	1 580	3·45	1 360	4·95
(c) 0·483 in.	40			2 237	0·69	2 000	1·21	1 734	2·01	1 555	2·77	1 349	4·04	1 179	5·71
(d) 82·3 lb.	60			1 882	0·82	1 663	1·46	1 431	2·43	1 287	3·35	1 133	4·81	1 016	6·62
(e) 646 lb.	80			1 538	1·01	1 349	1·79	1 168	2·98	1 065	4·04	966	5·64	891	7·55
(f) 0·331 ohm	122			912	1·70	837	2·89	783	4·45	756	5·69	731	7·46	713	9·44

Particulars of strand*	Temperature	240-ft. span		300-ft. span		400-ft. span		500-ft. span		600-ft. span		700-ft. span		900-ft. span	
(a) 0·1 sq. in.	22 (ice)	4 635	1·80	4 635	2·81	4 635	4·99	4 635	7·80	4 635	11·24	4 635	15·3	4 635	25·29
(b) 7/·173″ + 7/·076″	22 (no ice)	4 295	0·51	4 108	0·84	3 720	1·65	3 257	2·94	2 776	4·97	2 348	8·0	1 816	17·08
(c) 0·57 in.	40	3 842	0·57	3 661	0·94	3 290	1·86	2 863	3·34	2 444	5·64	2 100	8·94	1 695	18·30
(d) 88·00 lb.	60	3 342	0·66	3 170	1·09	2 828	2·17	2 457	3·90	2 122	6·5	1 870	9·98	1 583	19·60
(e) 919 lb.	80	2 849	0·77	2 692	1·28	2 393	2·56	2 095	4·57	1 852	7·45	1 681	11·15	1 486	20·88
(f) 0·245 ohm	122	1 864	1·18	1 773	1·94	1 629	3·76	1 517	6·31	1 441	9·57	1 388	13·52	1 325	23·40
(a) 0·125 sq. in.	22 (ice)	6 435	1·44	6 435	2·25	6 435	4·0	6 435	6·25	6 435	9·0	6 435	12·25	6 435	20·26
(b) 30/·093″+7/·093″	22 (no ice)	6 135	0·48	5 996	0·77	5 667	1·44	5 262	2·42	4 803	3·82	4 321	5·78	3 468	11·91
(c) 0·65 in.	40	5 564	0·53	5 413	0·85	5 097	1·60	4 714	2·7	4 293	4·28	3 869	6 46	3 165	13·05
(d) 93·35 lb.	60	4 915	0·60	4 768	0·96	4 476	1·82	4 128	3·09	3 761	4·88	3 411	7·33	2 875	14·36
(e) 1 224 lb.	80	4 271	0·69	4 138	1·11	3 873	2·11	3 573	3·57	3 276	5·61	3 010	8·30	2 630	15·7
(f) 0·198 ohm	122	2 956	0·99	2 872	1·60	2 722	3·0	2 577	4·95	2 456	7·48	2 359	10·58	2 232	18·5
(a) 0·15 sq. in.	22 (ice)	7 620	1·32	7 620	2·06	7 620	3·66	7 620	5·73	7 620	8·25	7 620	11·22	7 620	18·55
(b) 30/·102″+7/·102″	22 (no ice)	7 341	0·48	7 186	0·77	6 861	1·43	6 463	2·37	6 008	3·68	5 526	5·44	4 619	10·76
(c) 0·714 in.	40	6 631	0·53	6 482	0·85	6 173	1·59	5 801	2·64	5 386	4·10	4 962	6·06	4 210	11·81
(d) 97·65 lb.	60	5 847	0·6	5 708	0·97	5 423	1·81	5 092	3·01	4 734	4·67	4 385	6·86	3 813	13·04
(e) 1 472 lb.	80	5 069	0·7	4 945	1·12	4 697	2·09	4 419	3·47	4 134	5·34	3 873	7·76	3 472	14·32
(f) 0·165 ohm	122	3 489	1·01	3 426	1·62	3 313	2·96	3 204	4·79	3 108	7·11	3 029	9·93	2 917	17·04

* (a) = Copper equivalent cross-sectional area, sq. in. (b) = Number and diameter (in.) of strands. (c) = Overall diameter, in. (d) = Wind pressure (lb.) per 100 ft. (e) = Approximate weight (lb.) per 1 000 yards. (f) = Approximate resistance (ohms) per 1 000 yards at 60° F.

TABLE 7C.

Erection Sags and Tensions for Segmental Steel-cored Aluminium Conductors with $\frac{3}{8}$-in. Radial Ice Covering and 8 lb. per sq. ft. Wind Pressure on Projected Area. Factor of Safety = 2

Particulars of strand*	Temperature	100-ft. span		200-ft. span		300-ft. span		400-ft. span		500-ft. span		600-ft. span	
		Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip
	°F.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.
(*a*) 0·025 sq. in.	22 (ice)	1 140	0·82	1 140	3·28	1 140	7·36	1 140	13·1	1 140	20·5	1 140	29·5
(*b*) seg. + 1/·079"	22 (no ice)	1 036	0·0768	742	0·428	321	2·22	156	8·15	126	15·71	115	24·82
(*c*) 0·241 in.	40	936	0·085	645	0·492	262	2·72	145·5	8·74	122	16·29	112·5	25·30
(*d*) 66·06 lb.	60	819	0·97	532	0·597	212	3·38	136	9·42	118	16·83	110·5	25·87
(*e*) 190·5 lb.	80	703	0·113	424	0·75	177	4·03	127·5	9·98	114	17·4	108·5	26·28
(*f*) 0·9906 ohm	122	461	0·175	229	1·385	134	5·35	114	11·14	107	18·51	103·5	27·5
(*a*) 0·03 sq. in.	22 (ice)	1 321	0·73	1 321	2·92	1 321	6·57	1 321	11·7	1 321	18·25	1 321	26·3
(*b*) seg. + 1/·087"	22 (no ice)	1 221	0·0782	954	0·407	539	1·595	250	6·1	184	13·00	162	21·23
(*c*) 0·265 in.	40	1 102	0·0867	837	0·464	443	1·944	225	6·79	175	13·6	158	21·8
(*d*) 67·66 lb.	60	963	0·0992	705	0·0546	348	2·475	202	7·55	167	14·34	153	22·45
(*e*) 229·5 lb.	80	829	0·1152	567	0·0674	276	3·12	185	8·27	160	14·95	149	23·05
(*f*) 0·8236 ohm	122	532	0·1795	316	1·21	189	4·52	158	9·69	147	16·37	141	24·35
(*a*) 0·04 sq. in.	22 (ice)	1 735	0·59	1 735	2·36	1 735	5·3	1 735	9·45	1 735	14·8	1 735	20·3
(*b*) seg. + 1/·102"	22 (no ice)	1 645	0·079	1 410	0·368	1 028	1·14	602	3·45	380	8·56	307	15·22
(*c*) 0·307 in.	40	1 483	0·0875	1 250	0·415	880	1·33	509	4·08	349	9·325	293	15·94
(*d*) 70·46 lb.	60	1 293	0·1002	1 065	0·4875	713	1·64	425	4·88	318	10·2	278	16·78
(*e*) 312 lb.	80	1 105	0·1175	872	0·539	566	2·07	363	5·72	294	11·03	266	17·6
(*f*) 0·6109 ohm	122	717	0·1825	521	0·997	348	3·36	282	7·39	255	12·7	244	19·18
(*a*) 0·05 sq. in.	22 (ice)	2 315	0·469	2 315	1·875	2 315	4·22	2 315	7·5	2 315	11·71	2 315	16·8
(*b*) seg. + 7/·044"	22 (no ice)	2 241	0·075	2 056	0·325	1 748	0·86	1 343	1·98	925	4·5	672	8·92
(*c*) 0·348 in.	40	2 040	0·082	1 853	0·36	1 552	0·966	1 165	2·29	804	5·2	598	10·05
(*d*) 73·2 lb.	60	1 802	0·0925	1 619	0·412	1 325	1·13	970	2·75	685	6·07	543	11·05
(*e*) 400 lb.	80	1 572	0·106	1 385	0·48	1 105	1·36	798	3·34	592	7·05	496	12·05
(*f*) 0·4851 ohm	122	1 071	0·156	908	0·741	697	2·15	540	4·94	464	9·0	425	14·1
(*a*) 0·05 sq. in.	22 (ice)	2 250	0·491	1 250	1·97	2 250	4·42	2 250	7·87	2 250	12·3	2 250	17·7
(*b*) seg. + 1/·114"	22 (no ice)	2 181	0·074	2 004	0·325	1 665	0·882	1 236	2·09	816	5·05	573	10·18
(*c*) 0·344 in.	40	1 972	0·0825	1 790	0·363	1 450	1·035	1 052	2·45	702	5·82	526	11·12
(*d*) 72·93 lb.	60	1 735	0·094	1 555	0·418	1 237	1·182	865	2·99	606	6·76	483	12·1
(*e*) 390 lb.	80	1 500	0·108	1 318	0·494	1 015	1·44	727	3·66	530	7·74	446	13·11
(*f*) 0·4851 ohm	122	1 003	0·161	835	0·78	625	2·34	488	5·31	426	9·6	390	14·97
(*a*) 0·06 sq. in.	22 (ice)	2 602	0·434	2 602	1·738	2 602	3·9	2 602	6·95	2 602	10·86	2 602	15·61
(*b*) seg. + 1/·125"	22 (no ice)	2 538	0·770	2 340	0·333	2 036	0·864	1 630	1·92	1 190	4·1	868	8·1
(*c*) 0·377 in.	40	2 280	0·085	2 090	0·374	1 790	0·985	1 400	2·23	1 019	4·78	775	9·1
(*d*) 75·13 lb.	60	1 995	0·098	1 810	0·431	1 510	1·15	1 165	2·68	860	5·68	690	10·2
(*e*) 469 lb.	80	1 710	0·114	1 520	0·509	1 252	1·39	956	3·27	738	6·63	625	11·23
(*f*) 0·4048 ohm	122	1 110	0·175	967	0·80	778	2·25	640	4·88	566	8·63	528	13·33

(a) 0·075 sq. in.	22 (ice)	3 217	0·375	3 217	1·5	3 217	3·32	3 217	6·00	3 217	9·37	3 217	13·5
(b) seg. + 1/·140″	22 (no ice)	3 160	0·0772	2 965	0·321	2 720	0·808	2 320	1·654	1 895	3·21	1 435	6·14
(c) 0·422 in.	40	2 847	0·0857	2 663	0·365	2 422	0·906	2 050	1·87	1 639	3·72	1 264	6·97
(d) 78·13 lb.	60	2 495	0·098	2 312	0·421	2 070	1·055	1 730	2·21	1 382	4·4	1 100	8·0
(e) 586 lb.	80	2 412	0·114	1 972	0·494	1 739	1·26	1 438	2·67	1 167	5·22	972	8·92
(f) 0·3234 ohm	122	1 410	0·173	1 265	0·768	1 106	1·985	952	4·1	846	7·2	782	11·24
(a) 0·10 sq. in.	22 (ice)	3 700	0·354	3 700	1·42	3 700	3·19	3 700	5·68	3 700	8·86	3 700	12·78
(b) seg. + 7/·05	22 (no ice)	3 620	0·0854	3 450	0·360	3 140	0·89	2 750	1·835	2 260	3·43	1 830	6·1
(c) 0·487 in.	40	3 222	0·0962	3 040	0·408	2 742	1·018	2 338	2·21	1 939	4·0	1 596	7·0
(d) 82·46 lb.	60	2 780	0·1118	2 600	0·478	2 314	1·209	1 965	2·522	1 630	4·76	1 390	8·05
(e) 741 lb.	80	2 323	0·1338	2 165	0·575	1 900	1·47	1 615	3·075	1 370	5·66	1 236	9·05
(f) 0·2427 ohm	122	1 390	0·223	1 282	0·966	1 162	2·41	1 069	4·66	1 010	7·7	967	11·54
(a) 0·10 sq. in.	22 (ice)	4 288	0·312	4 288	1·25	4 288	2·815	4 288	5·0	4 288	7·81	4 288	11·27
(b) seg. + 7/·062″	22 (no ice)	4 240	0·0814	4 140	0·340	3 850	0·80	3 540	1·55	3 140	2·74	2 635	4·71
(c) 0·497 in.	40	3 820	0·0903	3 660	0·374	3 420	0·91	3 100	1·77	2 720	3·16	2 320	5·37
(d) 83·13 lb.	60	3 350	0·103	3 210	0·428	2 960	1·04	2 660	2·06	2 320	3·70	2 002	6·2
(e) 828 lb.	80	2 885	0·119	2 740	0·5	2 520	1·22	2 260	2·44	1 970	4·25	1 740	7·15
(f) 0·2427 ohm	122	1 920	0·18	1 810	0·761	1 670	1·86	1 530	3·51	1 412	6·11	1 330	9·34
(a) 0·125 sq. in.	22 (ice)	4 497	0·316	4 497	1·261	4 497	2·84	4 497	5·05	4 497	7·9	4 497	11·3
(b) seg. + 7/·06″	22 (no ice)	4 410	0·0865	4 235	0·36	3 930	0·875	3 521	1·73	3 052	3·13	2 427	5·67
(c) 0·544 in.	40	3 902	0·098	3 723	0·41	2 435	1·0	3 056	2·0	2 639	3·62	2 242	6·13
(d) 86·26 lb.	60	3 340	0·114	3 162	0·481	2 900	1·185	2 560	2·38	2 280	4·31	1 925	7·15
(e) 917 lb.	80	2 780	0·137	2 620	0·581	2 381	1·44	2 108	2·9	1 860	5·15	1 671	8·23
(f) 0·1941 ohm	122	1 605	0·238	1 532	0·995	1 450	2·37	1 381	4·45	1 336	7·15	1 305	10·55
(a) 0·125 sq. in.	22 (ice)	6 194	0·24	6 194	0·96	6 194	2·16	6 194	3·85	6 194	6·01	6 194	8·65
(b) seg. + 7/·08″	22 (no ice)	6 150	0·074	6 015	0·303	5 810	0·705	5 525	1·32	5 170	2·2	4 770	3·43
(c) 0·567 in.	40	5 570	0·0853	5 460	0·333	5 250	0·78	4 980	1·46	4 650	2·45	4 270	3·84
(d) 87·8 lb.	60	4 950	0·092	4 840	0·376	4 650	0·882	4 380	1·66	4 075	2·79	3 745	4·37
(e) 1 092 lb.	80	4 315	0·105	4 215	0·431	4 030	1·013	3 805	1·915	3 530	3·22	3 250	5·03
(f) 0·1941 ohm	122	3 020	0·151	2 935	0·62	2 815	1·456	2 670	2·73	2 528	4·5	2 405	6·82
(a) 0·15 sq. in.	22 (ice)	5 000	0·303	5 000	1·01	5 000	2·72	5 000	4·85	5 000	7·6	5 000	10·9
(b) seg. + 7/·066″	22 (no ice)	4 880	0·0945	4 705	0·393	4 355	0·95	3 945	1·87	3 459	3·34	2 975	5·58
(c) 0·592 in.	40	4 300	0·107	4 130	0·447	3 800	1·085	3 425	2·155	3 015	3·85	2 605	6·36
(d) 89·46 lb.	60	3 630	0·1265	3 415	0·534	3 165	1·305	2 842	2·60	2 520	4·58	2 245	7·4
(e) 1 105 lb.	80	2 965	0·155	2 805	0·67	2 580	1·605	2 335	3·16	2 120	5·45	1 955	8·5
(f) 0·1618 ohm	122	1 560	0·282	1 750	1·175	1 557	2·66	1 545	4·78	1 540	7·50	1 535	10·8
(a) 0·15 sq. in.	22 (ice)	7 000	0·228	7 000	0·91	7 000	2·05	7 000	3·64	7 000	5·7	7 000	8·2
(b) seg. + 7/·086″	22 (no ice)	6 930	0·078	6 810	0·317	6 600	0·74	6 305	1·37	5 960	2·26	5 548	3·5
(c) 0·615 in.	40	6 300	0·086	6 170	0·35	5 970	0·815	5 700	1·515	5 350	2·52	4 980	3·9
(d) 91·01 lb.	60	5 550	0·0975	5 440	0·398	5 240	0·93	4 980	1·70	4 680	2·88	4 353	4·46
(e) 1 295 lb.	80	4 815	0·112	4 695	0·46	4 518	1·076	4 300	2·05	4 045	3·35	3 778	5·15
(f) 0·1618 ohm	122	3 240	0·166	3 180	0·68	3 090	1·57	2 980	2·89	2 890	4·67	2 785	6·92

* (a) = Copper equivalent cross-sectional area, sq. in. (b) = Number and diameter (in.) of steel strands. (c) = Overall diameter, in. (d) = Wind pressure (lb.) per 100 ft. (e) = Approximate weight (lb.) per 1 000 yards. (f) = Approximate resistance (ohms) per 1 000 yards at 60° F.

TABLE 7D.

Erection Sags and Tensions for Cadmium-Copper Conductors (84 per cent conductivity) with $\frac{3}{8}$-in. Radial Ice Covering and 8 lb. per sq. ft. Wind Pressure on Projected Area. Factor of Safety = 2. Breaking Stress of Conductor = 2 × Tension at 22° F. with Wind and Ice.

Particulars of strand*	Temperature	200-ft. span		250-ft. span		300-ft. span		400-ft. span		500-ft. span		600-ft. span		700-ft. span	
		Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip
	° F.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.
(*a*) 0·025 sq. in.	22 (ice)	1 372	2·83	1 372	4·42	1 372	6·37	1 372	11·32	1 372	17·69				
(*b*) 3/·113″	22 (no ice)	1 084	0·54	928	1·0	750	1·77	441	5·36	316	11·69				
(*c*) 0·243 in.	40	993	0·60	840	1·1	670	1·99	403	5·87	302	12·24				
(*d*) 66·2 lb.	60	893	0·66	745	1·24	585	2·27	367	6·45	288	12·82				
(*e*) 354·8 lb.	80	795	0·74	653	1·41	511	2·61	337	7·02	275	13·44				
(*f*) 0·996 ohm	122	604	0·98	485	1·90	388	3·43	290	8·16	255	14·5				
(*a*) 0·04 sq. in.	22 (ice)	2 135	2·04	2 135	3·19	2 135	4·6	2 135	8·18	2 135	12·78	2 135	18·40		
(*b*) 3/·144″	22 (no ice)	1 898	0·51	1 767	0·85	1 613	1·34	1 261	3·05	944	6·37	750	11·52		
(*c*) 0·310 in.	40	1 749	0·55	1 621	0·92	1 472	1·47	1 142	3·37	867	6·94	708	12·21		
(*d*) 70·6 lb.	60	1 586	0·61	1 462	1·02	1 319	1·64	1 019	3·78	792	7·59	668	12·95		
(*e*) 576·2 lb.	80	1 424	0·67	1 304	1·15	1 171	1·84	907	4·24	727	8·27	632	13·66		
(*f*) 0·613 ohm	122	1 107	0·87	1 005	1·49	900	2·40	725	5·30	625	9·62	572	15·11		
(*a*) 0·05 sq. in.	22 (ice)	2 605	1·79	2 605	2·79	2 605	4·02	2 605	7·15	2 605	11·17	2 605	16·09		
(*b*) 3/·161″	22 (no ice)	2 382	0·50	2 260	0·83	2 115	1·28	1 775	2·70	1 425	5·26	1 158	9·33		
(*c*) 0·347 in.	40	2 198	0·55	2 078	0·90	1 938	1·39	1 615	2·97	1 304	5·75	1 079	10·0		
(*d*) 73·13 lb.	60	1 993	0·60	1 877	1·00	1 743	1·55	1 447	3·32	1 180	6·36	1 002	10·78		
(*e*) 720·3 lb.	80	1 791	0·67	1 680	1·11	1 555	1·74	1 291	3·72	1 074	6·98	937	11·53		
(*f*) 0·490 ohm	122	1 393	0·86	1 301	1·44	1 204	2·24	1 026	4·69	900	8·33	828	13·03		
(*a*) 0·06 sq. in.	22 (ice)	3 050	1·62	3 050	2·53	3 050	3·64	3 050	6·47	3 050	10·12	3 050	14·57	3 050	19·86
(*b*) 3/·176″	22 (no ice)	2 836	0·51	2 719	0·82	2 579	1·25	2 248	2·55	1 892	4·73	1 583	8·15	1 365	12·87
(*c*) 0·379 in.	40	2 615	0·55	2 500	0·90	2 366	1·36	2 052	2·79	1 730	5·17	1 470	8·78	1 290	13·61
(*d*) 75·26 lb.	60	2 371	0·60	2 261	0·99	2 133	1·51	1 844	3·11	1 565	5·72	1 355	9·53	1 214	14·45
(*e*) 860·8 lb.	80	2 129	0·67	2 025	1·10	1 907	1·69	1 649	3·48	1 420	6·31	1 255	10·28	1 149	15·28
(*f*) 0·411 ohm	122	1 656	0·87	1 572	1·42	1 482	2·17	1 310	4·38	1 180	7·59	1 090	11·83	1 038	16·90
(*a*) 0·075 sq. in.	22 (ice)	3 714	1·44	3 714	2·26	3 714	3·25	3 714	5·77	3 714	9·02	3 714	12·99	3 714	17·68
(*b*) 3/·197″	22 (no ice)	3 508	0·51	3 395	0·83	3 261	1·24	2 939	2·44	2 581	4·35	2 242	7·21	1 972	11·15
(*c*) 0·424 in.	40	3 231	0·56	3 122	0·90	2 993	1·35	2 690	2·67	2 365	4·75	2 075	7·78	1 850	11·90
(*d*) 78·86 lb.	60	2 926	0·61	2 822	0·99	2 701	1·49	2 422	2·97	2 141	5·24	1 905	8·48	1 728	12·73
(*e*) 1 078 lb.	80	2 623	0·68	2 527	1·11	2 416	1·67	2 171	3·31	1 939	5·78	1 750	9·23	1 620	13·57
(*f*) 0·328 ohm	122	2 032	0·88	1 959	1·43	1 881	2·15	1 725	4·16	1 599	7·02	1 505	10·72	1 440	15·27
(*a*) 0·1 sq. in.	22 (ice)	5 230	1·12	5 230	1·74	5 230	2·51	5 230	4·46	5 230	6·97	5 230	10·04	5 230	13·67
(*b*) 7/·148″	22 (no ice)	5 075	0·46	4 990	0·74	4 889	1·09	4 638	2·03	4 340	3·4	4 015	5·29	3 695	7·83
(*c*) 0·444 in.	40	4 709	0·50	4 627	0·80	4 529	1·17	4 291	2·20	4 015	3·67	3 720	5·71	3 440	8·41
(*d*) 79·6 lb.	60	4 302	0·55	4 225	0·87	4 134	1·28	3 914	2·41	3 665	4·02	3 410	6·23	3 170	9·12
(*e*) 1 416 lb.	80	3 899	0·60	3 828	0·96	3 744	1·42	3 549	2·66	3 335	4·42	3 120	6·81	2 935	9·84
(*f*) 0·2485 ohm	122	3 104	0·76	3 052	1·21	2 993	1·78	2 863	3·30	2 735	5·39	2 620	8·11	2 520	11·46
(*a*) 0·125 sq. in.	22 (ice)	6 420	1·01	6 420	1·58	6 420	2·28	6 420	4·05	6 420	6·33	6 420	9·12	6 420	12·42
(*b*) 7/·166″	22 (no ice)	6 268	0·47	6 185	0·75	6 085	1·10	5 840	2·03	5 546	3·35	5 225	5·11	4 895	7·42
(*c*) 0·498 in.	40	5 806	0·51	5 727	0·81	5 633	1·18	5 403	2·20	5 135	3·62	4 845	5·5	4 555	7·97
(*d*) 83·2 lb.	60	5 295	0·56	5 222	0·89	5 136	1·30	4 938	2·42	4 690	3·95	4 445	6·01	4 205	8·64
(*e*) 1 782 lb.	80	4 788	0·62	4 722	0·98	4 647	1·43	4 466	2·66	4 265	4·35	4 070	6·56	3 880	9·36
(*f*) 0·1973 ohm	122	3 789	0·78	3 749	1·24	3 705	1·80	3 600	3·30	3 500	5·30	3 410	7·83	3 330	10·90
(*a*) 0·15 sq. in.	22 (ice)	7 547	0·95	7 547	1·48	7 547	2·14	7 547	3·8	7 547	5·93	7 547	8·54	7 547	11·63
(*b*) 7/·182″	22 (no ice)	7 395	0·48	7 312	0·76	7 210	1·11	6 965	2·05	6 673	3·35	6 351	5·06	6 020	7·27
(*c*) 0·546 in.	40	6 840	0·52	6 762	0·83	6 670	1·20	6 445	2·20	6 185	3·62	5 893	5·46	5 600	7·81
(*d*) 86·4 lb.	60	6 227	0·57	6 155	0·91	6 080	1·32	5 875	2·43	5 645	3·97	5 405	5·95	5 175	8·45
(*e*) 2 142 lb.	80	5 617	0·64	5 560	1·00	5 485	1·46	5 320	2·69	5 140	4·35	4 950	6·5	4 775	9·17
(*f*) 0·1638 ohm	122	4 420	0·81	4 390	1·27	4 360	1·84	4 290	3·33	4 215	5·30	4 150	7·75	4 085	10·71

* (*a*) = Copper equivalent cross-sectional area, sq. in. (*b*) = Number and diameter (in.) of strands. (*c*) = Overall diameter, in. (*d*) = Wind pressure (lb.) per 100 ft. (*e*) = Approximate weight (lb.) per 1 000 yards. (*f*) = Approximate resistance (ohms) per 1 000 yards at 60° F.

TABLE 7E.

Erection Sags and Tensions for Copperweld Extra-High-Strength (30 per cent Conductivity) Conductors with $\frac{3}{8}$-in. Radial Ice Covering and 8 lb. per sq. ft. Wind Pressure on Projected Area. Minimum Factor of Safety = 5 at tension for 60° F.*

Particulars of strand†	Temperature	240-ft. span		300-ft. span		360-ft. span		400-ft. span		450-ft. span		500-ft. span		600-ft. span	
		Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip
	° F.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.
(a) 0·0129 sq. in.	22 (ice)	901	5·19	1 000	7·30	1 094	9·61	1 095	11·86	1 095	15·01	1 095	18·52	1 095	26·68
(b) 1/·128″	22 (no ice)	521	0·63	519	0·99	518	1·43	399	2·29	248	4·67	178	8·03	122	16·9
(c) 0·128 in.	40	482	0·68	480	1·07	480	1·54	364	2·51	237	4·95	167	8·56	117	17·55
(d) 58·5 lb.	60	438	0·75	438	1·17	438	1·69	327	2·79	214	5·41	156	9·15	115	17·89
(e) 137 lb.	80	396	0·83	396	1·30	398	1·86	293	3·12	195	5·95	147	9·72	112	18·36
(f) 6·28 ohms	122	308	1·07	312	1·65	317	2·34	230	3·97	163	7·11	132	10·84	106	19·40
(g) 2 190 lb.															
(a) 0·0163 sq. in.	22 (ice)	1 026	4·68	1 132	6·63	1 234	8·77	1 299	10·27	1 335	12·65	1 335	15·62	1 335	22·49
(b) 1/·144″	22 (no ice)	638	0·65	636	1·02	634	1·48	632	1·83	548	2·67	402	4·49	232	11·19
(c) 0·144 in.	40	588	0·71	587	1·11	586	1·60	585	1·98	503	2·91	368	4·91	221	11·78
(d) 59·6 lb.	60	534	0·78	534	1·22	534	1·75	534	2·17	453	3·23	333	5·41	209	12·41
(e) 173·3 lb.	80	480	0·87	481	1·35	482	1·94	483	2·40	412	3·55	303	5·96	199	13·04
(f) 4·99 ohms	122	371	1·12	376	1·73	382	2·45	386	3·00	330	4·43	251	7·18	182	14·3
(g) 2 670 lb.															
										500-ft. span		600-ft. span		700-ft. span	
(a) 0·0201 sq. in.	22 (ice)	1 160	4·26	1 271	6·07	1 380	8·05	1 449	9·46	1 590	13·48	1 590	19·42	1 590	26·43
(b) 1/·160″	22 (no ice)	764	0·67	761	1·05	758	1·52	756	1·88	705	3·16	436	7·34	302	14·43
(c) 0·160 in.	40	703	0·73	701	1·14	699	1·65	698	2·04	651	3·42	404	7·92	289	15·08
(d) 60·66 lb.	60	636	0·81	636	1·26	636	1·81	636	2·24	594	3·75	373	8·58	276	15·79
(e) 213·5 lb.	80	571	0·90	572	1·40	574	2·01	576	2·47	540	4·16	347	9·22	265	16·45
(f) 4·05 ohms	122	438	1·17	444	1·80	453	2·55	459	3·10	440	5·06	301	10·77	244	17·85
(g) 3 180 lb.															
(a) 0·0249 sq. in.	22 (ice)	1 294	3·93	1 413	5·63	1 527	7·50	1 600	8·83	1 775	12·44	1 840	17·27	1 840	23·5
(b) 1/·176″	22 (no ice)	890	0·70	887	1·09	883	1·58	880	1·95	872	3·09	688	5·64	476	11·03
(c) 0·176 in.	40	817	0·76	815	1·19	813	1·72	810	2·12	806	3·34	635	6·13	449	11·71
(d) 61·73 lb.	60	736	0·84	736	1·32	736	1·90	736	2·33	736	3·66	582	6·66	422	12·44
(e) 258·5 lb.	80	657	0·95	660	1·47	662	2·11	664	2·59	669	4·05	534	7·27	399	13·17
(f) 3·34 ohms	122	499	1·24	509	1·91	520	2·69	527	3·26	545	4·94	451	8·61	358	14·68
(g) 3 680 lb.															
(a) 0·0289 sq. in.	22 (ice)	1 438	3·53	1 566	5·21	1 685	6·98	1 764	8·23	1 947	11·65	2 119	15·4	2 130	20·93
(b) 1/·192″	22 (no ice)	1 034	0·72	1 030	1·12	1 025	1·62	1 022	2·01	1 011	3·17	1 001	4·61	747	8·42
(c) 0·192 in.	40	948	0·79	945	1·22	942	1·77	940	2·19	934	3·44	929	4·97	697	9·02
(d) 62·8 lb.	60	852	0·88	852	1·36	852	1·95	852	2·41	852	3·77	852	5·42	647	9·72
(e) 308 lb.	80	759	0·98	761	1·52	765	2·17	768	2·68	774	4·15	781	5·91	602	10·45
(f) 2·81 ohms	122	572	1·30	584	1·98	598	2·78	607	3·39	629	5·10	650	7·11	524	12·0
(g) 4 260 lb.															
(a) 0·0379 sq. in.	22 (ice)	1 766	3·32	1 903	4·82	2 036	6·48	2 121	7·68	2 326	10·94	2 519	14·55	2 657	18·78
(b) 3/·128″	22 (no ice)	1 344	0·75	1 339	1·18	1 332	1·70	1 327	2·11	1 314	3·33	1 300	4·84	1 285	6·67
(c) 0·276 in.	40	1 235	0·82	1 232	1·28	1 228	1·85	1 225	2·28	1 218	3·59	1 211	5·20	1 202	7·13
(d) 68·4 lb.	60	1 116	0·90	1 116	1·41	1 116	2·03	1 116	2·51	1 116	3·91	1 116	5·64	1 116	7·68
(e) 419 lb.	80	998	1·01	1 002	1·57	1 007	2·25	1 010	2·77	1 019	4·29	1 027	6·13	1 035	8·28
(f) 2·14 ohms	122	763	1·32	780	2·02	798	2·84	809	3·46	837	5·22	864	7·28	888	9·65
(g) 5 580 lb.															
(a) 0·0479 sq. in.	22 (ice)	2 076	3·00	2 220	4·40	2 361	5·92	2 452	7·04	2 672	10·10	2 877	13·50	3 070	17·24
(b) 3/·144″	22 (no ice)	1 648	0·77	1 641	1·21	1 633	1·75	1 626	2·17	1 609	3·43	1 589	5·01	1 569	6·91
(c) 0·310 in.	40	1 511	0·84	1 507	1·32	1 502	1·91	1 498	2·36	1 489	3·71	1 478	5·38	1 467	7·38
(d) 70·6 lb.	60	1 362	0·94	1 362	1·46	1 362	2·10	1 362	2·60	1 362	4·05	1 362	5·84	1 362	7·95
(e) 530 lb.	80	1 214	1·05	1 220	1·63	1 227	2·34	1 230	2·88	1 243	4·48	1 253	6·35	1 264	8·57
(f) 1·698 ohms	122	921	1·38	945	2·10	968	2·96	983	3·60	1 021	5·40	1 055	7·54	1 086	9·97
(g) 6 810 lb.															

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* This class of wire will carry 0·54 of the d.c. amperes of a copper conductor of the same diameter for the same temperature-rise. Sags calculated so that tension at 60° F. does not exceed 1/5th of breaking stress, so as to reduce tendency to vibration.

† (a) = Actual cross-sectional area, sq. in. (b) = Number and diameter (in.) of strands. (c) = Overall diameter, in. (d) = Wind pressure (lb.) per 100 ft. (e) = Approximate weight (lb.) per 1 000 yards. (f) = Approximate resistance (ohms) per 1 000 yards at 60° F. (g) = Breaking stress of conductor lb.

TABLE 7F.

Erection Sags and Tensions for Copperweld High-Strength (40 per cent conductivity) Conductors with $\frac{3}{8}$-in. Radial Ice Covering and 8 lb. per sq. ft. Wind Pressure on Projected Area. Minimum Factor of Safety = 5 at Tension for 60° F.*

Particulars of strand†	Temperature	240-ft. span		300-ft. span		360-ft. span		400-ft. span		450-ft. span		500-ft. span		600-ft. span	
		Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip
	° F.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.
(*a*) 0·0479 sq. in. (*b*) 3/·144″ (*c*) 0·310 in. (*d*) 70·66 lb. (*e*) 530 lb. (*f*) 1·272 ohms (*g*) 5 100 lb.	22 (ice)	1 832	3·40	1 990	4·89	2 127	6·58	2 165	7·98	2 327	9·39	2 429	1·10	2 550	15·25
	22 (no ice)	1 292	0·99	1 288	1·54	1 259	2·28	1 247	2·84	1 233	3·63	1 218	4·53	1 086	7·32
	40	1 160	1·10	1 163	1·71	1 142	2·51	1 135	3·12	1 127	3·97	1 120	4·83	1 011	7·87
	60	1 020	1·25	1 020	1·95	1 020	2·81	1 020	3·47	1 020	4·39	1 020	5·41	937	8·49
	80	887	1·43	900	2·21	908	3·15	915	3·87	921	4·86	931	5·93	870	9·14
	122	647	1·97	683	2·91	714	4·01	734	4·82	757	5·91	778	7·10	757	10·50
(*a*) 0·0379 sq. in. (*b*) 3/·128″ (*c*) 0·276 in. (*d*) 68·4 lb. (*e*) 419 lb. (*f*) 1·606 ohms (*g*) 4 160 lb.	22 (ice)	1 572	3·73	1 716	5·34	1 851	7·13	1 937	8·41	2 039	10·12	2 080	12·24	2 080	17·61
	22 (no ice)	1 048	0·96	1 037	1·52	1 025	2·21	1 016	2·75	1 004	3·53	903	4·84	659	9·55
	40	944	1·07	938	1·68	930	2·44	926	3·02	919	3·85	830	5·26	621	10·13
	60	832	1·21	832	1·89	832	2·73	832	3·36	832	4·26	757	5·77	583	10·79
	80	725	1·39	733	2·15	741	3·06	746	3·75	752	4·71	692	6·31	550	11·43
	122	529	1·90	556	2·83	581	3·90	597	4·69	615	5·76	582	7·51	493	12·76
(*a*) 0·0312 sq. in. (*b*) 3/·116″ (*c*) 0·250 in. (*d*) 66·66 lb. (*e*) 343 lb. (*f*) 1·955 ohms (*g*) 3 490 lb.	22 (ice)	1 389	4·05	1 525	5·76	1 652	7·65	1 732	9·01	1 745	11·31	1 745	13·96	1 745	20·11
	22 (no ice)	877	0·94	869	1·48	859	2·16	851	2·69	699	4·15	563	6·36	415	12·41
	40	791	1·04	786	1·63	780	2·38	776	2·95	638	4·55	521	6·87	397	12·97
	60	698	1·18	698	1·84	698	2·66	698	3·28	578	5·02	481	7·44	379	13·68
	80	610	1·35	616	2·08	622	2·98	626	3·66	525	5·52	446	8·02	363	14·17
	122	446	1·85	468	2·74	488	3·80	500	4·58	437	6·63	388	9·22	335	15·37
(*a*) 0·0250 sq. in. (*b*) 3/·104″ (*c*) 0·224 in. (*d*) 64·96 lb. (*e*) 276 lb. (*f*) 2·450 ohms (*g*) 2 880 lb.	22 (ice)	1 218	4·42	1 345	6·25	1 440	8·41	1 440	10·38	1 440	13·14	1 440	16·22	1 440	20·35
	22 (no ice)	721	0·92	713	1·45	663	2·25	524	3·52	395	5·9	320	9·0	253	16·39
	40	652	1·02	647	1·60	602	2·48	475	3·88	365	6·39	303	9·5	246	16·85
	60	576	1·15	576	1·80	537	2·78	427	4·31	337	6·93	286	10·05	239	17·36
	80	504	1·31	508	2·04	478	3·12	385	4·78	312	7·47	272	10·59	232	17·87
	122	370	1·79	386	2·69	376	3·97	316	5·83	272	8·58	246	11·67	219	18·90
(*a*) 0·0194 sq. in. (*b*) 3/·092″ (*c*) 0·198 in. (*d*) 63·2 lb. (*e*) 216 lb. (*f*) 3·136 ohms (*g*) 2 290 lb.	22 (ice)	1 054	4·91	1 145	7·05	1 145	10·15	1 145	12·53	1 145	15·85	1 145	19·58	1 145	28·2
	22 (no ice)	571	0·98	517	1·58	318	3·68	241	5·98	192	9·50	168	13·58	146	22·22
	40	517	1·09	466	1·75	288	4·06	224	6·43	184	9·93	163	13·79	144	22·60
	60	458	1·23	413	1·97	259	4·32	208	6·92	176	10·40	158	14·25	141	23·00
	80	402	1·40	363	2·24	235	4·98	195	7·39	168	10·85	154	14·68	139	23·4
	122	296	1·90	277	2·94	197	5·94	173	8·34	155	11·75	145	15·55	134	24·23
(*a*) 0·0147 sq. in. (*b*) 3/·08″ (*c*) 0·172 in. (*d*) 61·46 lb. (*e*) 163 lb (*f*) 4·130 ohms (*g*) 1 760 lb.	22 (ice)	880	5·64	880	8·82	880	12·7	880	15·68	880	19·85	880	24·5		
	22 (no ice)	394	1·00	195	3·13	121	7·27	104	10·42	93	14·75	87	19·5		
	40	354	1·11	175	3·5	116	7·63	101	10·76	92	15·05	86	19·8		
	60	311	1·26	157	3·9	110	8·02	98	11·13	89	15·40	85	20·12		
	80	271	1·45	142	4·33	105	8·39	95	11·47	88	15·74	83	20·45		
	122	199	1·97	119	5·15	97	9·14	89	12·19	84	16·40	81	21·10		

(a) 0·0289 sq. in.	22 (ice)	1 305	4·00	1 433	5·7	1 555	7·56	1 600	9·10	1 600	11·52	1 600	14·22	1 600	20·48
(b) 1/·192″	22 (no ice)	814	0·92	805	1·43	795	2·09	733	2·80	575	4·52	462	6·96	349	13·24
(c) 0·192 in.	40	730	1·02	725	1·59	719	2·34	663	3·10	524	4·96	429	7·48	335	13·80
(d) 62·8 lb.	60	640	1·17	640	1·81	640	2·60	592	3·47	474	5·48	396	8·11	321	14·44
(e) 308 lb.	80	554	1·35	560	2·06	566	2·94	528	3·89	431	6·03	371	8·65	309	14·95
(f) 2·11 ohms	122	398	1·87	419	2·76	438	3·80	419	4·91	361	7·19	324	9·91	286	16·15
(g) 3 200 lb.															
(a) 0·0201 sq. in.	22 (ice)	1 064	4·64	1 179	6·55	1 190	9·34	1 190	11·53	1 190	14·59	1 190	18·01	1 190	25·94
(b) 1/·160″	22 (no ice)	598	0·86	593	1·35	404	2·85	300	4·75	229	7·86	194	11·45	163	19·69
(c) 0·160 in.	40	539	0·95	536	1·49	362	3·19	274	5·20	216	8·35	187	11·92	160	20·20
(d) 60·66 lb.	60	476	1·08	476	1·68	320	3·60	250	5·70	203	8·86	179	12·40	156	20·55
(e) 213·5 lb.	80	415	1·23	418	1·91	285	4·05	229	6·21	192	9·37	173	12·88	153	21·00
(f) 3·03 ohms	122	300	1·71	313	2·56	229	5·00	196	7·26	174	10·36	160	13·86	146	21·90
(g) 2 380 lb.															
		300-ft. span		360-ft. span		400-ft. span		450-ft. span		500-ft. span		600-ft. span		700-ft. span	
(a) 0·0886 sq. in.	22 (ice)	3 201	3·58	3 357	4·91	3 458	5·89	3 580	7·20	3 692	8·61	3 918	11·68	4 119	15·15
(b) 7/·128″	22 (no ice)	2 556	1·41	2 529	2·08	2 512	2·59	2 487	3·31	2 462	4·13	2 414	6·06	2 368	8·31
(c) 0·384 in.	40	2 314	1·56	2 299	2·29	2 289	2·84	2 275	3·62	2 262	4·48	2 236	6·55	2 213	9·00
(d) 75·6 lb.	60	2 056	1·76	2 056	2·56	2 056	3·16	2 056	4·00	2 056	4·95	2 056	7·12	2 056	9·68
(e) 976 lb.	80	1 813	1·99	1 830	2·88	1 842	3·53	1 855	4·44	1 869	5·44	1 894	7·72	1 917	10·38
(f) 0·686 ohm	122	1 370	2·64	1 426	3·70	1 462	4·45	1 504	5·47	1 542	6·59	1 611	9·08	1 669	11·93
(g) 10 280 lb.															
(a) 0·0725 sq. in.	22 (ice)	2 770	3·85	2 921	5·26	3 020	6·28	3 137	7·66	3 252	9·12	3 466	12·32	3 664	15·85
(b) 7/·116″	22 (no ice)	2 130	1·41	2 111	2·04	2 096	2·54	2 078	3·25	2 059	4·04	2 021	5·93	1 984	8·22
(c) 0·348 in.	40	1 935	1·56	1 924	2·24	1 916	2·78	1 905	3·54	1 895	4·39	1 875	6·39	1 856	8·78
(d) 73·2 lb.	60	1 726	1·73	1 726	2·50	1 726	3·09	1 726	3·91	1 726	4·82	1 726	6·94	1 726	9·45
(e) 799 lb.	80	1 526	1·96	1 540	2·80	1 549	3·44	1 560	4·32	1 571	5·30	1 591	7·54	1 609	10·15
(f) 0·835 ohm	122	1 162	2·56	1 206	3·58	1 235	4·31	1 268	5·32	1 300	6·40	1 355	8·84	1 402	11·64
(g) 8 630 lb.															
(a) 0·0585 sq. in.	22 (ice)	2 379	4·19	2 524	5·69	2 618	6·78	2 735	8·21	2 841	9·75	3 047	13·10	3 236	16·8
(b) 7/·104″	22 (no ice)	1 752	1·37	1 737	2·00	1 726	2·48	1 712	3·16	1 697	4·06	1 665	5·78	1 639	8·0
(c) 0·312 in.	40	1 594	1·51	1 585	2·19	1 579	2·71	1 572	3·45	1 563	4·40	1 545	6·23	1 533	8·55
(d) 70·8 lb.	60	1 424	1·69	1 424	2·44	1 424	3·01	1 424	3·80	1 424	4·83	1 424	6·76	1 424	9·21
(e) 643 lb.	80	1 262	1·91	1 273	2·72	1 279	3·39	1 289	4·20	1 296	5·31	1 309	7·36	1 326	9·88
(f) 1·046 ohms	122	961	2·51	997	3·47	1 019	4·20	1 045	5·18	1 069	6·44	1 110	8·67	1 152	11·38
(g) 7 120 lb.															
(a) 0·0458 sq. in.	22 (ice)	2 009	4·65	2 145	6·27	2 236	7·43	2 343	8·96	2 446	10·60	2 640	14·15	2 818	18·03
(b) 7/·092″	22 (no ice)	1 392	1·35	1 380	1·97	1 372	2·44	1 361	3·12	1 350	3·88	1 328	5·68	1 305	7·87
(c) 0·276 in.	40	1 267	1·49	1 261	2·15	1 256	2·67	1 251	3·39	1 244	4·21	1 233	6·12	1 220	8·42
(d) 68·4 lb.	60	1 134	1·66	1 134	2·39	1 134	2·96	1 134	3·74	1 134	4·62	1 134	6·65	1 134	9·06
(e) 503 lb.	80	1 006	1·87	1 015	2·68	1 020	3·29	1 026	4·14	1 032	5·07	1 045	7·22	1 056	9·72
(f) 1·34 ohms	122	768	2·46	797	3·41	812	4·13	832	5·10	851	6·15	887	8·50	920	11·16
(g) 5 670 lb.															
(a) 0·0346 sq. in.	22 (ice)	1 672	5·24	1 800	7·01	1 883	8·27	1 982	9·94	2 077	11·71	2 175	16·11	2 175	21·92
(b) 7/·08″	22 (no ice)	1 066	1·32	1 057	1·94	1 052	2·41	1 044	3·07	1 036	3·82	887	6·42	670	11·56
(c) 0·240 in.	40	972	1·46	967	2·12	964	2·63	959	3·34	955	4·14	823	6·92	634	12·24
(d) 66 lb.	60	870	1·64	870	2·36	870	2·91	870	3·68	870	4·55	759	7·50	599	12·94
(e) 380 lb.	80	774	1·84	779	2·63	783	3·24	788	4·07	793	4·99	703	8·10	567	13·67
(f) 1·765 ohms	122	590	2·41	610	3·36	623	4·07	638	5·02	653	6·06	600	9·49	511	15·17
(g) 4 350 lb.															

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* This class of conductor will carry 0·63 of the d.c. amperes of a copper conductor of the same diameter for the same temperature-rise. Sags calculated so that tension at 60° F. does not exceed 1/5th of breaking stress, so as to reduce tendency to vibration.

† (a) = Actual cross-sectional area, sq. in. (b) = Number and diameter (in.) of strands. (c) = Overall diameter, in. (d) = Wind pressure (lb.) per 100 ft. (e) = Approximate weight (lb.) per 1 000 yards. (f) = Approximate resistance (ohms) per 1 000 yards at 60° F. (g) = Breaking stress of conductor, lb.

TABLE 7G.

Erection Sags and Tensions for Galvanized-Steel Conductors (7/12 and 7/14 S.W.G., 45 tons per sq. in.) with $\frac{3}{8}$-in. Radial Ice Covering and 8 lb. per sq. ft. Wind Pressure on Projected Area. Factor of Safety = **2.**

Particulars of strand*	Temperature	200-ft. span		300-ft. span		400-ft. span		450-ft. span		500-ft. span		550-ft. span		600-ft. span	
		Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip
	°F.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.
(*a*) 0·0585 sq. in.	22 (ice)	2 766	1·590	2 766	3·594	2 766	6·37	2 766	8·08	2 766	9·96	2 766	12·05	2 766	14·35
(*b*) 7/·104″	22 (no ice)	2 507	0·410	2 195	1·051	1 796	2·29	1 593	3·27	1 399	4·7	1 232	6·31	1 108	8·34
(*c*) 0·312 in.	40	2 321	0·442	2 017	1·153	1 637	2·50	1 451	3·579	1 281	5·01	1 140	6·81	1 038	8·90
(*d*) 70·8 lb.	60	2 117	0·485	1 822	1·275	1 469	2·85	1 306	3·980	1 163	5·517	1 050	7·40	968	9·54
(*e*) 616 lb.	80	1 912	0·536	1 629	1·419	1 312	3·13	1 176	4·420	1 061	6·04	972	7·98	908	10·17
(*f*) 3·53 ohms	122	1 492	0·688	1 257	1·837	1 035	3·97	954	5·448	890	7·21	841	9·24	806	11·47
		200-ft. span		300-ft. span		360-ft. span		400-ft. span		450-ft. span					
(*a*) 0·0346 sq. in.	22 (ice)	1 633	2·38	1 633	5·35	1 633	7·69	1 633	9·52	1 633	12·03				
(*b*) 7/·08″	22 (no ice)	1 282	0·474	881	1·55	641	3·07	522	4·66	432	7·16				
(*c*) 0·24 in.	40	1 174	0·518	787	1·74	575	3·42	478	5·08	406	7·69				
(*d*) 66 lb.	60	1 054	0·576	689	1·985	512	3·84	436	5·56	381	8·09				
(*e*) 365 lb.	80	935	0·650	601	2·28	459	4·29	402	6·04	360	8·56				
(*f*) 5·95 ohms	122	697	0·872	453	3·02	376	5·23	346	7·025	323	9·53				

TABLE 7H.

Erection Sags and Tensions for Copper-cored Steel Conductors (7/12 and 7/14 S.W.G.) with $\frac{3}{8}$-in. Radial Ice Covering and 8 lb. per sq. ft. Wind Pressure on Projected Area. Factor of Safety = 2.

Particulars of strand*	Temperature	100-ft. span		200-ft. span		300-ft. span		400-ft. span		500-ft. span	
		Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip
	°F.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.
(*a*) 0·0585 sq. in.	22 (ice)	2 615	0·421	2 615	1·68	2 615	3·8	2 615	6·7	2 615	10·5
(*b*) 7/·104″	22 (no ice)	2 533	0·103	2 332	0·475	2 000	1·175	1 590	2·61	1 215	5·37
(*c*) 0·312 in.	42	2 316	0·112	2 105	0·496	1 785	1·31	1 410	2·96	1 095	5·96
(*d*) 70·8 lb.	62	2 087	0·125	1 885	0·555	1 580	1·49	1 245	3·36	997	6·56
(*e*) 627 lb.	82	1 860	0·140	1 665	0·626	1 380	1·705	1 100	3·8	910	7·17
(*f*) 1·595 ohms	122	1 405	0·186	1 240	0·844	1 030	2·29	870	4·8	778	8·40
(*a*) 0·0346 sq. in.	22 (ice)	1 551	0·623	1 551	2·48	1 551	5·6	1 551	9·98		
(*b*) 7/·08″	22 (no ice)	1 455	0·106	1 180	0·524	764	1·82	456	5·42		
(*c*) 0·24 in.	42	1 331	0·116	1 056	0·535	670	2·08	416	5·94		
(*d*) 66 lb.	62	1 207	0·128	911	0·68	580	2·4	385	6·42		
(*e*) 371·5 lb.	82	1 083	0·143	820	0·754	500	2·76	358	6·90		
(*f*) 2·888 ohms	122	836	0·185	600	1·03	393	3·55	318	7·76		

* (*a*) = Actual cross-sectional area, sq. in. (*b*) = Number and diameter (in.) of strands. (*c*) = Overall diameter, in. (*d*) = Wind pressure (lb.) per 100 ft. (*e*) = Approximate weight (lb.) per 1 000 yards. (*f*) = Approximate resistance (ohms) per 1 000 yards at 60° F.

TABLE 7J.

Erection Sags and Tensions for Hard-Drawn Solid Copper Conductors with $\frac{3}{16}$-in. Radial Ice Covering and 8 lb. per sq. ft. Wind Pressure on Projected Area. Factor of Safety = 2. Breaking Stress of Conductor = 2 × Tension at 22° F. with Wind and Ice.

Particulars of strand*	Temperature	100-ft. span		120-ft. span		150-ft. span		180-ft. span		210-ft. span		240-ft. span	
		Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip
	° F.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.
(*a*) 0·0201 sq. in.	22 (ice)	618	0·79	618	1·137	618	1·78	618	2·56	618	3·48	618	4·55
(*b*) 1/·160″	22 (no ice)	561	0·173	536	0·26	491	0·44	438	0·72	381	1·12	322	1·73
(*c*) 0·160 sq. in.	40	502	0·193	477	0·293	433	0·50	383	0·82	330	1·30	278	2·00
(*d*) 35·66 lb.	60	435	0·222	413	0·338	371	0·59	324	0·97	278	1·54	237	2·36
(*e*) 232·5 lb.	80	371	0·261	349	0·400	310	0·70	270	1·16	233	1·83	204	2·74
(*f*) 1·227 ohms	122	240	0·404	224	0·623	200	1·09	180	1·74	166	2·58	155	3·60
(*a*) 0·0289 sq. in.	22 (ice)	866	0·618	866	0·889	866	1·389	866	2·0	866	2·72	866	3·56
(*b*) 1/·192″	22 (no ice)	817	0·171	796	0·253	758	0·415	712	0·64	660	0·93	604	1·33
(*c*) 0·192 in.	40	732	0·191	711	0·283	674	0·466	630	0·72	581	1·06	530	1·52
(*d*) 37·8 lb.	60	637	0·22	617	0·326	582	0·54	542	0·84	498	1·24	454	1·77
(*e*) 334·8 lb.	80	543	0·257	525	0·383	493	0·638	458	0·99	421	1·46	387	2·08
(*f*) 0·8432 ohm	122	354	0·395	343	0·586	324	0·97	307	1·48	292	2·11	280	2·875
(*a*) 0·0499 sq. in.	22 (ice)	1 437	0·445	1 437	0·641	1 437	1·0	1 437	1·44	1 437	1·96	1 437	2·56
(*b*) 1/·252″	22 (no ice)	1 397	0·172	1 379	0·251	1 347	0·402	1 309	0·60	1 266	0·84	1 218	1·14
(*c*) 0·252 in.	40	1 250	0·192	1 233	0·281	1 203	0·450	1 167	0·67	1 127	0·94	1 083	1·28
(*d*) 41·8 lb.	60	1 087	0·221	1 071	0·323	1 045	0·518	1 013	0·77	977	1·09	940	1·47
(*e*) 576·7 lb.	80	926	0·260	913	0·379	889	0·609	863	0·90	835	1·27	806	1·72
(*f*) 0·4937 ohm	122	600	0·400	597	0·580	591	0·916	585	1·33	581	1·83	576	2·40
(*a*) 0·0598 sq. in.	22 (ice)	1 688	0·408	1 688	0·587	1 688	0·917	1 688	1·321	1 688	1·80	1 688	2·35
(*b*) 1/·276″	22 (no ice)	1 649	0·175	1 632	0·255	1 602	0·405	1 565	0·60	1 523	0·84	1 476	1·125
(*c*) 0·276 in.	40	1 472	0·196	1 457	0·285	1 428	0·454	1 395	0·67	1 356	0·94	1 314	1·26
(*d*) 43·4 lb.	60	1 277	0·225	1 263	0·329	1 238	0·524	1 209	0·77	1 176	1·08	1 141	1·46
(*e*) 691·8 lb.	80	1 084	0·266	1 073	0·387	1 053	0·616	1 030	0·91	1 005	1·27	980	1·70
(*f*) 0·4114 ohm	122	696	0·414	697	0·596	698	0·930	699	1·336	700	1·82	700	2·375
(*a*) 0·0707 sq. in.	22 (ice)	1 956	0·379	1 956	0·546	1 956	0·853	1 956	1·227	1 956	1·67	1 956	2·18
(*b*) 1/·300″	22 (no ice)	1 918	0·178	1 902	0·258	1 872	0·409	1 836	0·60	1 795	0·84	1 750	1·12
(*c*) 0·300 in.	40	1 709	0·199	1 694	0·290	1 667	0·460	1 635	0·68	1 598	0·94	1 558	1·26
(*d*) 45 lb.	60	1 479	0·230	1 466	0·335	1 443	0·531	1 416	0·78	1 385	1·08	1 353	1·45
(*e*) 817·3 lb.	80	1 252	0·272	1 242	0·395	1 225	0·625	1 205	0·92	1 184	1·27	1 163	1·69
(*f*) 0·3480 ohm	122	796	0·428	802	0·612	809	0·947	816	1·35	824	1·82	831	2·36
(*a*) 0·0824 sq. in.	22 (ice)	2 244	0·256	2 244	0·512	2 244	0·801	2 244	1·152	2 244	1·57	2 244	2·05
(*b*) 1/·324″	22 (no ice)	2 207	0·180	2 191	0·261	2 161	0·413	2 126	0·606	2 086	0·84	2 041	1·12
(*c*) 0·324 in.	40	1 964	0·202	1 949	0·294	1 923	0·465	1 892	0·68	1 857	0·94	1 818	1·25
(*d*) 46·6 lb.	60	1 695	0·234	1 684	0·340	1 662	0·538	1 637	0·79	1 610	1·09	1 570	1·46
(*e*) 953·3 lb.	80	1 431	0·278	1 423	0·402	1 408	0·635	1 392	0·93	1 375	1·27	1 357	1·69
(*f*) 0·2983 ohm	122	902	0·44	912	0·628	927	0·964	942	1·366	956	1·83	970	2·36
(*a*) 0·0951 sq. in.	22 (ice)	2 538	0·339	2 538	0·489	2 538	0·763	2 538	1·10	2 538	1·50	2 538	1·95
(*b*) 1/·348″	22 (no ice)	2 502	0·183	2 486	0·266	2 457	0·420	2 422	0·61	2 382	0·85	2 338	1·13
(*c*) 0·348 in.	40	2 222	0·206	2 208	0·299	2 182	0·473	2 152	0·69	2 118	0·96	2 081	1·27
(*d*) 48·2 lb.	60	1 913	0·240	1 902	0·347	1 882	0·549	1 859	0·80	1 834	1·10	1 806	1·46
(*e*) 1 100 lb.	80	1 608	0·285	1 602	0·412	1 591	0·649	1 578	0·94	1 565	1·29	1 551	1·70
(*f*) 0·2584 ohm	122	1 004	0·456	1 019	0·648	1 042	0·99	1 065	1·39	1 088	1·86	1 109	2·38
(*a*) 0·1087 sq. in.	22 (ice)	2 853	0·325	2 853	0·468	2 835	0·731	2 853	1·052	2 853	1·43	2 853	1·87
(*b*) 1/·372″	22 (no ice)	2 816	0·186	2 800	0·27	2 771	0·426	2 737	0·62	2 697	0·86	2 653	1·14
(*c*) 0·372 in.	40	2 496	0·210	2 482	0·304	2 458	0·480	2 429	0·70	2 395	0·97	2 359	1·28
(*d*) 49·8 lb.	60	2 144	0·244	2 134	0·353	2 115	0·558	2 095	0·81	2 071	1·12	2 047	1·48
(*e*) 1 257 lb.	80	1 796	0·292	1 791	0·421	1 784	0·661	1 775	0·96	1 766	1·31	1 756	1·72
(*f*) 0·2261 ohm	122	1 110	0·472	1 131	0·668	1 163	1·013	1 195	1·42	1 226	1·88	1 255	2·40

* (*a*) = Actual cross-sectional area, sq. in. (*b*) = Number and diameter (in.) of strands. (*c*) = Overall diameter, in. (*d*) = Wind pressure (lb.) per 100 ft. (*e*) = Approximate weight (lb.) per 1 000 yards. (*f*) = Approximate resistance (ohms) per 1 000 yards at 60° F.

TABLE 7K.

Erection Sags and Tensions for Hard-Drawn Stranded Copper Conductors (7-strand) with $\frac{3}{16}$-in. Radial Ice Covering and 8 lb. per sq. ft. Wind Pressure on Projected Area. Factor of Safety = 2.

Particulars of strand*	Temperature	100-ft. span		120-ft. span		150-ft. span		180-ft. span		210-ft. span		240-ft. span	
		Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip
	°F.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.
(*a*) 0·0221 sq. in.	22 (ice)	686	0·761	686	1·096	686	1·712	686	2·466	686	3·36	686	4·39
(*b*) 7/·064″	22 (no ice)	628	0·176	603	0·264	557	0·446	504	0·71	444	1·09	383	1·66
(*c*) 0·192 in.	40	563	0·196	538	0·295	494	0·503	443	0·81	387	1·26	333	1·91
(*d*) 37·8 lb.	60	490	0·225	466	0·341	424	0·586	377	0·95	329	1·48	285	2·23
(*e*) 2 648 lb.	80	419	0·264	396	0·401	358	0·694	316	1·13	278	1·76	244	2·60
(*f*) 1·116 ohms	122	274	0·403	258	0·616	234	1·063	212	1·68	196	2·49	184	3·45
(*a*) 0·0346 sq. in.	22 (ice)	1 062	0·558	1 062	0·803	1 062	1·254	1 062	1·805	1 062	2·46	1 062	3·21
(*b*) 7/·08″	22 (no ice)	1 015	0·170	995	0·250	958	0·405	914	0·61	864	0·88	808	1·23
(*c*) 0·24 in.	40	912	0·189	892	0·278	856	0·453	814	0·69	767	0·99	715	1·39
(*d*) 41·0 lb.	60	798	0·216	779	0·319	745	0·521	706	0·79	663	1·15	618	1·61
(*e*) 413·8 lb.	80	683	0·252	667	0·372	636	0·61	602	0·93	565	1·35	530	1·875
(*f*) 0·7143 ohm	122	453	0·381	443	0·560	426	0·91	409	1·36	394	1·93	380	2·61
(*a*) 0·0457 sq. in.	22 (ice)	1 397	0·468	1 397	0·673	1 397	1·051	1 397	1·515	1 397	2·06	1 397	2·69
(*b*) 7/·092″	22 (no ice)	1 355	0·168	1 337	0·246	1 304	0·394	1 265	0·584	1 219	0·83	1 169	1·12
(*c*) 0·276 in.	40	1 226	0·186	1 207	0·272	1 175	0·437	1 138	0·650	1 095	0·92	1 048	1·25
(*d*) 43·4 lb.	60	1 709	0·211	1 063	0·309	1 033	0·497	999	0·740	961	1·05	920	1·40
(*e*) 547·2 lb.	80	935	0·244	920	0·357	894	0·574	865	0·855	831	1·21	797	1·65
(*f*) 0·54 ohm	122	640	0·356	633	0·519	620	0·828	606	1·220	593	1·70	580	2·27
(*a*) 0·0585 sq. in.	22 (ice)	1 771	0·407	1 771	0·586	1 771	0·915	1 771	1·317	1 771	1·794	1 771	2·343
(*b*) 7/·104″	22 (no ice)	1 733	0·168	1 716	0·245	1 686	0·389	1 649	0·573	1 607	0·80	1 560	1·08
(*c*) 0·312 in.	40	1 562	0·187	1 545	0·272	1 517	0·433	1 483	0·638	1 443	0·89	1 401	1·20
(*d*) 45·8 lb.	60	1 372	0·213	1 357	0·310	1 331	0·493	1 301	0·726	1 266	1·02	1 229	1·37
(*e*) 699·3 lb.	80	1 184	0·246	1 171	0·360	1 150	0·570	1 124	0·840	1 096	1·17	1 066	1·58
(*f*) 0·4225 ohm	122	799	0·365	795	0·528	790	0·831	784	1·205	778	1·65	771	2·18
(*a*) 0·1 sq. in.	22 (ice)	2 936	0·319	2 936	0·459	2 936	0·718	2 936	1·033	2 936	1·406	2 936	1·84
(*b*) 7/·136″	22 (no ice)	2 901	0·172	2 887	0·249	2 859	0·392	2 826	0·572	2 789	0·79	2 746	1·05
(*c*) 0·408 in.	40	2 606	0·191	2 593	0·277	2 568	0·437	2 539	0·636	2 506	0·88	2 469	1·16
(*d*) 52·2 lb.	60	2 279	0·219	2 268	0·317	2 248	0·499	2 225	0·726	2 199	1·00	2 170	1·32
(*e*) 1 196 lb.	80	1 955	0·255	1 948	0·369	1 935	0·580	1 920	0·831	1 903	1·15	1 885	1·52
(*f*) 0·2469 ohm	122	1 298	0·384	1 307	0·549	1 320	0·850	1 335	1·210	1 350	1·63	1 365	2·11

* (*a*) = Actual cross-sectional area, sq. in. (*b*) = Number and diameter (in.) of strands. (*c*) = Overall diameter, in. (*d*) = Wind pressure (lb.) per 100 ft. (*e*) = Approximate weight (lb.) per 1 000 yards. (*f*) = Approximate resistance (ohms) per 1 000 yards at 60° F.

TABLE 7L.

Erection Sags and Tensions for 7-strand Hard-Drawn Copper Conductors with $\frac{3}{16}$-in. Radial Ice Covering and 8 lb. per sq. ft. Wind Pressure on Projected Area. Basis: A sag of 3 ft. 6 in. on 180-ft. span at 122° F.

Particulars of strand*	Temperature	100-ft. span		120-ft. span		150-ft. span		180-ft. span		210-ft. span		240-ft. span	
		Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip
	° F.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.
(*a*) 0·0221 sq. in.	22 (ice)	477·5	1·09	477·5	1·577	477·5	2·46	477·5	3·50	477·5	4·82	477·5	6·30
(*b*) 7/·064″	22 (no ice)	359·5	0·306	313·0	0·506	241·0	1·02	186·0	1·913	154·9	3·132	137·6	4·64
(*c*) 0·192 in.	40	297·5	0·369	256·2	0·619	198·5	1·25	161·0	2·210	140·2	3·460	128·5	4·925
(*d*) 37·8 lb.	60	233·5	0·472	200·6	0·790	162·0	1·53	139·7	2 560	127 3	3·807	120 2	5·265
(*e*) 264·8 lb.	80	177·7	0·622	156·5	1·007	135·5	1·828	124·0	2·807	117·2	4·145	113·1	5·620
(*f*) 1·116 ohms	122	103·5	1·062	102·8	1·520	102·0	2·430	101·8	3·500	101·5	4·78	101·3	6·26
(*g*) 1 372 lb.													
(*a*) 0·058 sq. in.	22 (ice)	845·0	0·854	845·0	1·230	845·0	1·92	845·0	2·766	845·0	3·760	845·0	4·91
(*b*) 7/·104″	22 (no ice)	690·0	0·422	635·0	0·661	557·5	1·176	496·0	1·910	456·0	2·765	425·4	3·95
(*c*) 0·312 in.	40	545·5	0·534	507·9	0·826	462·0	1·432	423·5	2·226	406·0	3·165	390·0	4·31
(*d*) 45·8 lb.	60	411·6	0·708	397·5	1·055	382·0	1·730	371·7	2·543	364·0	3·530	359·0	4·675
(*e*) 699·3 lb.	80	316·0	0·921	320·3	1·318	326·0	2·010	329·3	2·870	332·6	3·850	334·0	5·040
(*f*) 0·4225 ohm	122	210·0	1·386	229·5	1·825	252·8	2·592	270·0	3·500	283·0	4·530	293·0	5·735
(*g*) 3 542 lb.													
(*a*) 0·1 sq. in.	22 (ice)	1 221·0	0·7678	1 221	1·105	1 221	1·72	1 221	2·48	1 221	3·38	1 221	4·42
(*b*) 7/·136″	22 (no ice)	1 047·0	0·476	989	0·726	909	1·235	845·0	1·911	798·5	2·75	765·5	3·75
(*c*) 0·408 in.	40	818·0	0·609	790	0·910	755·0	1·485	732·0	2·210	712·0	3·08	699·0	4·106
(*d*) 52·2 lb.	60	618·5	0·806	624·5	1·150	630·0	1·779	634·0	2·545	637·0	3·45	640·0	4·489
(*e*) 1 196 lb.	80	484·0	1·030	511·0	1·405	540·5	2·075	562·0	2·870	575·5	3·815	592·0	4·855
(*f*) 0·2496 ohm	122	336·0	1·483	375·0	1·912	423·0	2·650	461·5	3·500	491·5	4·470	516·0	5·560
(*g*) 5 872 lb.													

TABLE 7M.

Erection Sags and Tensions for 7-strand Hard-Drawn Copper Conductors with $\frac{3}{16}$-in. Radial Ice Covering and 8 lb. per sq. ft. Wind Pressure on Projected Area. Basis : A Sag of 3 ft. on 180-ft. Span at 122° F.

Particulars of strand *	Temperature	100-ft. span		120-ft. span		150-ft. span		180-ft. span		210-ft. span		240-ft. span	
		Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip	Tension	Dip
	° F.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	lb.	ft.	ft.	lb.
(*a*) 0·0221 sq. in.	22 (ice)	527·2	0·990	527·2	1·425	527·2	2·225	527·2	3·204	527·2	4·37	527·2	5·697
(*b*) 7/·064″	22 (no ice)	430·0	0·256	389·8	0·407	322·0	0 767	255	1·400	204·6	2·371	174·2	3·640
(*c*) 0·192 in.	40	367·0	0·300	329·0	0·482	268·0	0·922	215	1·660	179·3	2·707	158·0	4·000
(*d*) 37·8 lb.	60	298·0	0·369	265·0	0·600	216·2	1·145	180	1·980	157·5	3·079	144·5	4·382
(*e*) 264·8 lb.	80	234·0	0·470	207·6	0·763	175·0	1·411	154·0	2·318	141·0	3·439	133·4	4·750
(*f*) 1·116 ohms	122	131·0	0·840	126·3	1·259	121·9	2·029	119·0	3·000	116·9	4·15	115·4	5·490
(*g*) 1 372 lb.													
(*a*) 0·058 sq. in.	22 (ice)	989·0	0·716	989·0	1·05	989	1·64	989	2·36	989	3·22	989	4·21
(*b*) 7/·104″	22 (no ice)	871	0·343	825·0	0·509	747·4	0·878	675·4	1·40	611·5	2·11	563	2·985
(*c*) 0·312 in.	40	711·7	0·408	674·8	0·621	617	1·062	568·5	1·668	530	2·424	501·1	3·350
(*d*) 45·8 lb.	60	549·0	0·530	528·0	0·792	498·1	1·315	476·5	1·985	459·5	2·80	447·0	3·750
(*e*) 699·3 lb.	80	414·6	0·702	412·5	1·017	409	1·602	407	2 319	406·0	3·17	404·6	4·159
(*f*) 0·4225 ohm	122	250·0	1·162	270·6	1·550	295·5	2·220	314·2	3·000	329·0	3·90	341·0	4·925
(*g*) 3 542 lb.													
(*a*) 0·1 sq. in.	22 (ice)	1 484·2	0·623	1 484·2	0·909	1 484·2	1·42	1 484·2	2·045	1 484·2	2·776	1 484·2	3·630
(*b*) 7/·104″	22 (no ice)	1 356·8	0·367	1 309·0	0·548	1 230·0	0·912	1 154·5	1·398	1 086·0	2·020	1 030·0	2·788
(*c*) 0·408 in.	40	1 092·8	0·456	1 061·5	0·676	1 014·5	1·105	973·0	1·660	938·5	2·34	911·0	3·152
(*d*) 52·2 lb.	60	833·5	0·598	828·0	0·867	821·0	1·366	815·0	1·980	810	2·711	807·0	3·558
(*e*) 1 196 lb.	80	630·5	0·791	651·0	1·013	676·5	1·659	794·6	2·340	713·0	3·080	726·0	3·956
(*f*) 0·2496 ohm	122	395·4	1·259	439·0	1·634	494	2·279	538	3·00	574·9	3·83	604·5	4·75
(*g*) 5 872 lb.													

* (*a*) = Actual cross-sectional area, sq. in. (*b*) = Number and diameter (in.) of strands. (*c*) = Overall diameter, in. (*d*) = Wind pressure (lb.) per 100 ft. (*e*) = Approximate weight (lb.)per 1 000 yards. (*f*) = Approximate resistance (ohms) per 1 000 yards at 60° F. (*g*) = Breaking stress of conductor lb.

(7) POLE FOUNDATIONS.

As mentioned in the Introduction, the question of providing adequate earth foundations has become increasingly important now that the loads which may be applied to single wood poles have been considerably increased (the old factor of safety was 10, against the present 3·5). Thus, almost invariably on span lengths exceeding 300 ft. for high-voltage lines, either single or double kicking-blocks are necessary if the depth of setting is not to exceed 6 ft. in normal ground. Ground varies considerably in different localities, and a wide variation in the value of the earth resistance may occur even in a given field. For normal ground, however, 1 000 lb. per sq. ft. per ft. of depth may safely be taken as an average value for depths up to 7 or 8 ft.

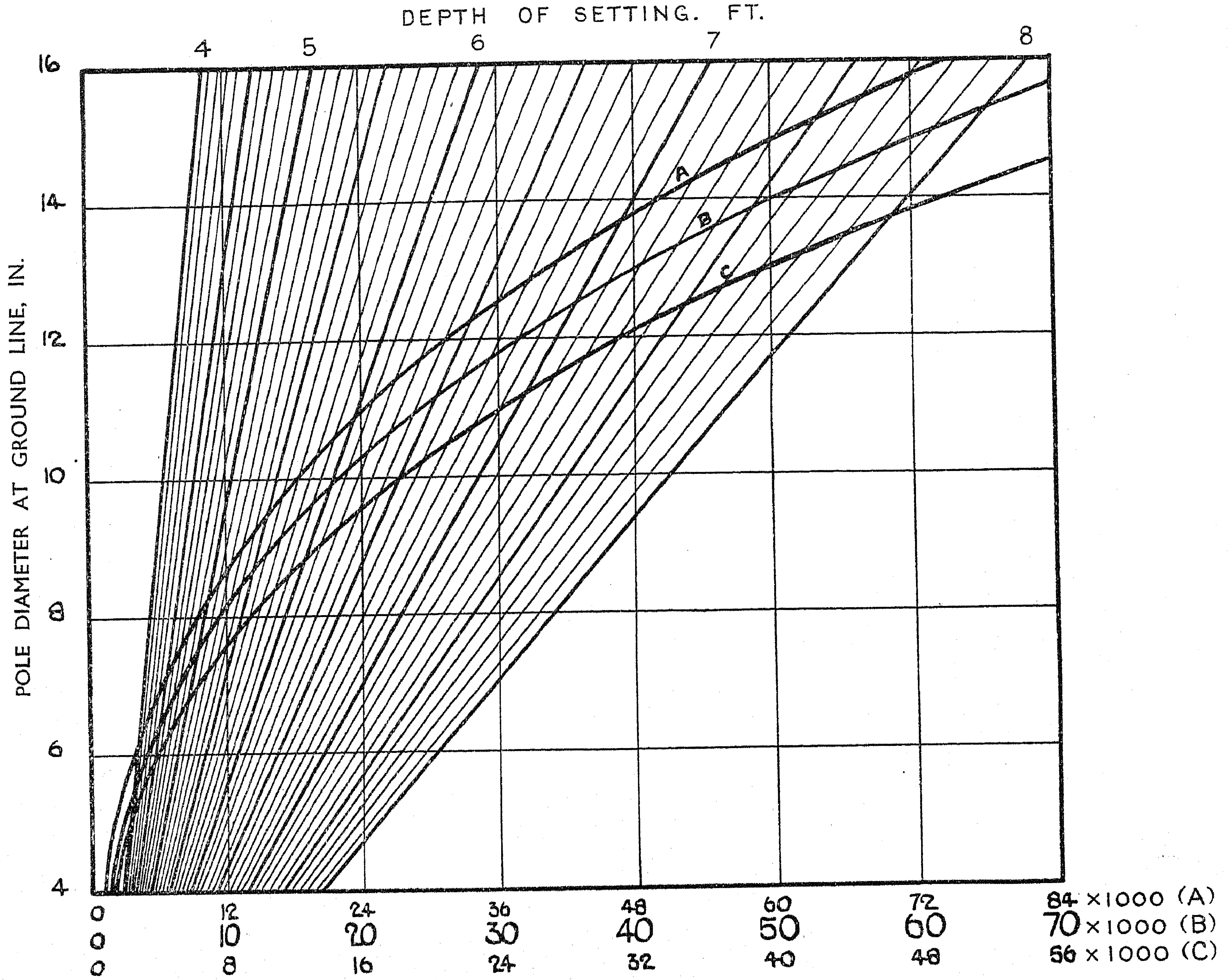


FIG. 4A.—Depths of setting for single red-fir poles when buried in different types of soil, A, B, or C, and safe working load at ground line for red-fir poles.

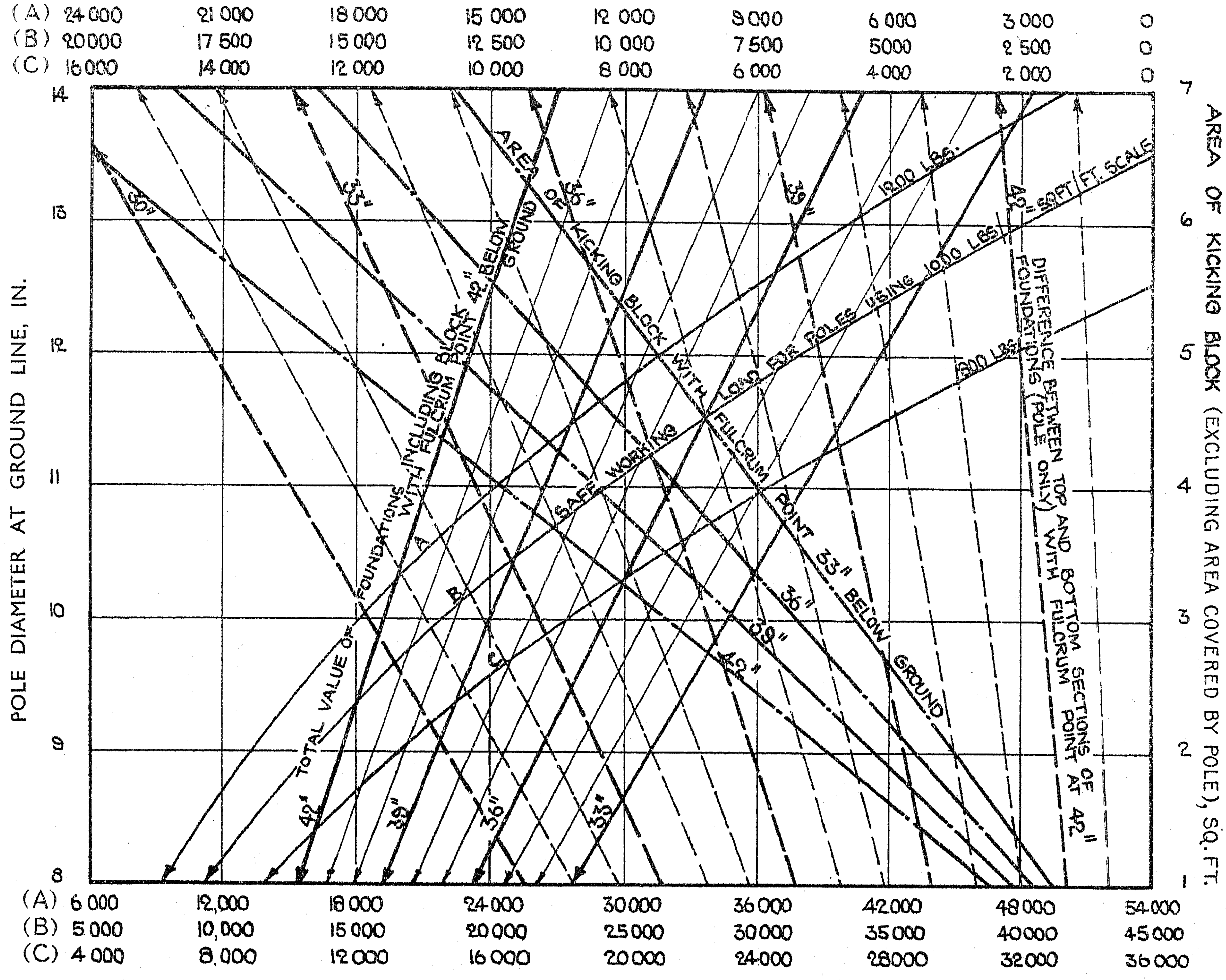
(A) 1 200 lb. per sq. ft. per ft. of depth
(B) 1 000 lb. per sq. ft. per ft. of depth } assuming a factor of safety of 2·5.
(C) 800 lb. per sq. ft. per ft. of depth

A series of graphs (Figs. 4A to 4F inclusive) have been prepared relating to foundations for single poles, single poles with single kicking-block, and values which may be added for double kicking-blocks only. In all cases the graphs are arranged so that safe values of either 800, 1 000, or 1 200 lb. per sq. ft. per ft. of depth may be selected. Should this range not cover the class of ground encountered, other basic values may easily be substituted, assuming uniform increase in ground resistance with depth. Further, in dealing with the safe working load for wood poles, a factor of safety of 3·5 has been allowed, whereas in the case of foundations a factor of safety of 2·5 only has been taken. This should ensure that, in case of failure, the foundation would give before the breaking of the pole; which, in the author's opinion, is desirable.

Fig. 4A.

The curved graphs A, B, C, represent the safe working loads at ground line for poles of varying diameters. The safe loading which a pole of any diameter from 4 in. to 16 in. at the ground line can carry may be read directly.

Example.—Take a 12 in. diameter pole on the left-hand vertical scale and follow along the horizontal to curves A, B, or C. Immediately below the points of intersection with any one of these curves the value 31 500 lb. ft. will appear on the lower scales relating to curves A, B, and C respectively. The three curves A, B, and C also show the depths of setting which are required in the three different classes of earth, for single poles having ground diameters of 4 in. to 16 in., to ensure foundation values[*] suitable to the pole strengths at ground line (excluding the slight difference in the factor of safety already referred to). Thus to find the depth of setting necessary for a pole of 12 in. diameter at ground line to be erected in ground having a safe bearing value of 1 000 lb. per sq. ft. per ft. of depth, proceed as follows: Read the diameter 12 in. on the left-hand vertical scale, and follow along horizontally to the point of intersection with curve B. From the point of intersection follow the diagonal line to the top horizontal scale, and read the depth of setting, viz. 6·8 ft. Should the value of the earth resistance be 1 200 lb. per sq. ft. per ft. of depth, follow the diagonal upwards from the point of intersection with curve A, and read 6·4 ft.; or, for ground of 800 lb. per sq. ft. per ft., follow the diagonal upwards from the point of intersection with curve C, and read 7·33 ft.



Safe working load at ground line for red-fir poles (lb.-ft.) and total value of foundations (lb.-ft.), including kicking-block, with fulcrum point at various depths. (NOTE.—This total value excludes any allowance for taper below ground line, thus compensating for graphs A, B, and C, being plotted on values of safe working load, instead of total values of foundations.)

FIG. 4B.—Area of kicking-blocks required (excluding area covered by pole) for poles having diameters at ground line from 8 in. to 14 in., when poles are buried 5 ft. 6 in. deep, to provide foundation values suitable to the pole strength.

Curves (A), (B), and (C), as in Fig. 4A.

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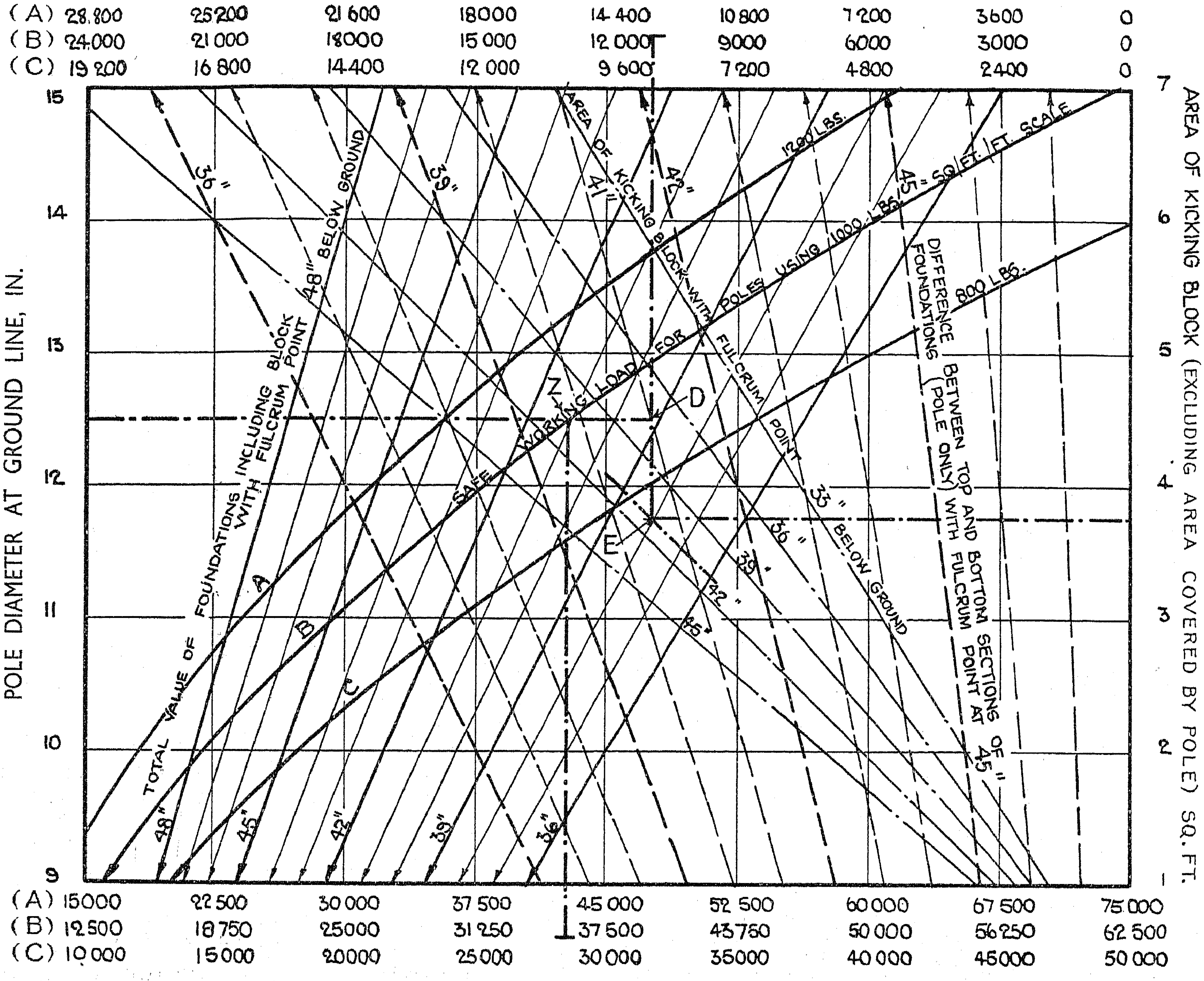
[*] The term "foundation value" implies "the total moment of resistance of the foundation."

Figs. 4*B*, 4*C*, 4*D*, *and* 4*E*.

This series of graphs indicates the sizes of single kicking-blocks which are required on single poles to develop foundation values suitable to the pole strengths. The four graphs are based on depths of pole settings of 5 ft. 6 in., 6 ft., 6 ft. 6 in., and 7 ft.; they cover a range of pole diameters at ground line from 8 in. to 17 in., and apply to ground having safe values of 800, 1 000, or 1 200 lb. per sq. ft. per ft. of depth.

The author was unable to simplify the graphs further, in view of the number of variables involved, viz. (i) variable depths of fulcrum point, (ii) variable depth of kicking block, (iii) variable value per sq. ft. of ground at kicking block, (iv) variable length of lever arm between fulcrum point and kicking block, (v) variable size of kicking block. When the graphs have been used a number of times, the principle becomes comparatively easy to apply. In order to simplify reading, arrows have been fixed where possible to show the scales to which the individual graphs refer.

Taking the graph for a 6-ft. depth of pole setting (Fig. 4c), the full-line diagonals having arrows at the bottom represent the total values of the foundations (bottom horizontal scales) for any pole from 9 in. to 15 in. diameter complete with single kicking-block, with the fulcrum point at various depths from 36 in. to 48 in. below ground, excluding allowance for taper below ground line. It is evident that for maximum efficiency this total value should be suitable to the pole strength. The broken-line diagonals with arrows at the top represent the differences in value between the top section of the foundations due to the pole only, and the bottom section



Safe working load at ground line for red-fir poles (lb.-ft.) (factor of safety 3·5), and total value of foundations (lb.-ft.), including kicking-block, with fulcrum point at various depths. (NOTE.—This total value excludes any allowance for taper below ground line, thus compensating for Graphs A, B, and C, being plotted on values of safe working load, instead of total value of foundations.)

FIG. 4c.—Area of kicking-blocks required (excluding area covered by pole) for pole shaving diameters at ground line from 9 in. to 15 in., when poles are buried 6 ft. deep, to provide foundation values suitable to the pole strength.

Curves (A) (B), and (C), as in Fig. 4A.

(top horizontal scales) with the fulcrum points at various depths from 36 in. to 45 in. This value is evidently that to be taken care of by the kicking block, the size of which can be read from the broken-line diagonals, starting from the bottom right-hand corner.

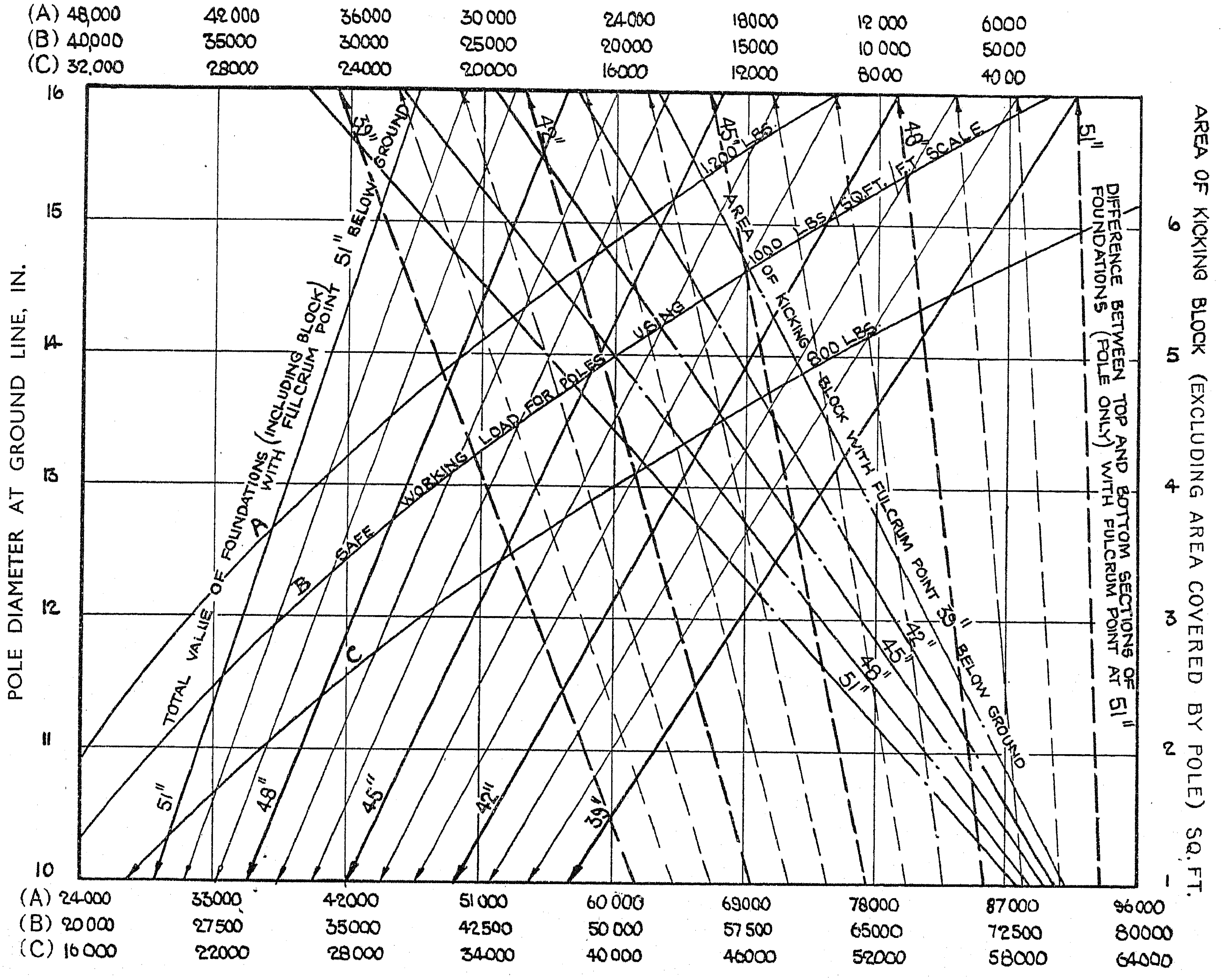
Example.—To find the size of single kicking-block required for use with a pole having a diameter at ground line of 12½ in. and buried 6 ft. deep in ground having an average safe bearing value of 1 000 lb. per sq. ft. per ft. of depth, Fig. 4c is employed as follows:—

(1) Read the diameter of the pole at ground line on the left-hand vertical scale, viz. 12½ in., and follow along horizontally to the point of intersection (Z) with curve B (1 000 lb. per sq. ft. per ft.). Directly under this point is found the value of the pole strength on the middle scale of the bottom horizontal figures, viz. 35 600 lb. ft. approximately.

(2) A foundation value suitable to this can be developed if the fulcrum point is arranged to be at the depth indicated by the full-line diagonal at the point of intersection Z (running downwards towards the left of the figure), viz. 41 in.

(3) The difference in value between top and bottom sections of foundation due to a 12½-in. pole only, when the fulcrum point is 41 in. deep, is found by following down the dotted-line diagonal for 41 in. (viz. 6th dotted diagonal with arrows at top from top left-hand corner) until one is horizontally opposite the diameter 12½ in. on the left-hand vertical scale. Directly above the point of intersection D read on the top horizontal scales (middle set) 11 000 lb. ft.

(4) Follow vertically downwards from point D to point of intersection with the diagonal for size of kicking block with pole fulcrum-point 41 in. below ground,



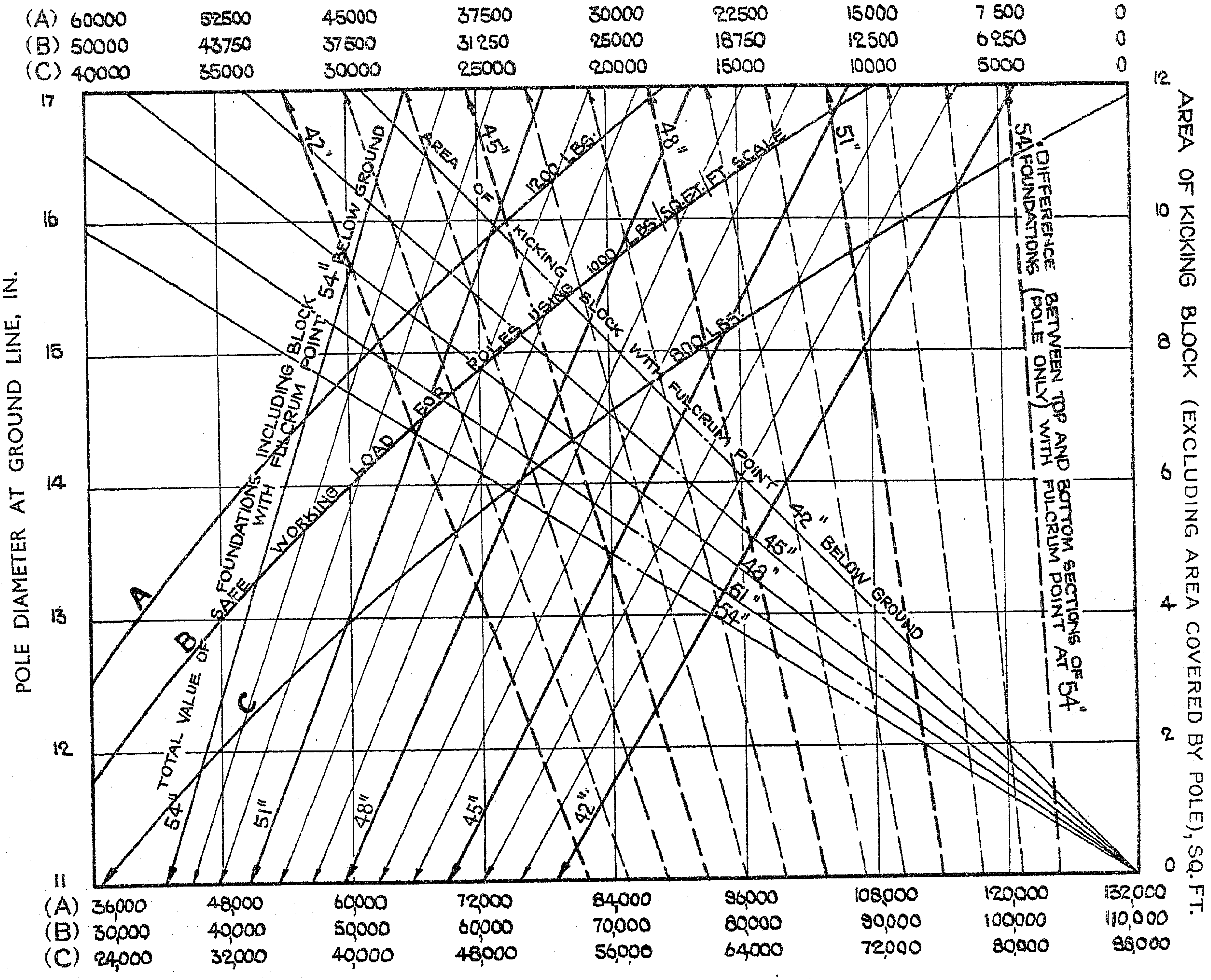
Safe working load at ground line for red-fir poles (lb.-ft.) (factor of safety 3·5), and total value of foundations (lb.-ft.), including kicking-block, with fulcrum point at various depths. (NOTE.—This total value of foundations excludes any allowance for taper below ground line, thus compensating for graphs A, B, and C, being plotted on values of safe working load, instead of total value of foundations.)

FIG. 4D.—Area of kicking-blocks required (excluding area covered by pole) for poles having diameters at ground line from 10 in. to 16 in., when poles are buried 6 ft. 6 in. deep to provide foundation values suitable to the pole strength.

Curves (A), (B), and (C), as in Fig. 4A.

viz. point E. From this point follow horizontally to the right, and read off 3·75 sq. ft. as the area of kicking block required, excluding the area covered by the pole.

In all normal cases the best depth below ground to the centre of the single kicking-blocks may be taken as half the depth of the fulcrum point.



Safe working load at ground line for red-fir poles (lb.-ft.) (factor of safety 3·5), and total value of foundations (lb.-ft.), including kicking-block, with fulcrum point at various depths. (Note.—This total value of foundations excludes any allowance for taper below ground line, thus compensating for Graphs A, B, and C, being plotted on values of safe working load, instead of total value of foundations.)

Fig. 4E.—Area of kicking-blocks required (excluding area covered by pole) for poles having diameters at ground line from 11 in. to 17 in., when poles are buried 7 ft. deep, to provide foundation values suitable to pole strength.

Curves (A), (B), and (C), as in Fig. 4A.

Curves A or C may be similarly used in conjunction with the appropriate horizontal scales for ground values of 800 or 1 200 lb. per sq. ft. per ft. of depth respectively.

Fig. 4F.

In softer ground, double kicking-blocks are often required, and Fig. 4F indicates the area of top and bottom blocks, together with the best depth for the top block, to provide certain additional values of earth resistance.

Example.—The following is the method of finding the sizes of double kicking-blocks necessary to make the foundation as strong as the pole, in the case of a 14-in. pole buried 6 ft. deep in earth having a safe value of 1 000 lb. per sq. ft. per ft. of depth. From Fig. 4A, the safe load for the pole is 50 000 lb. ft. The value of the foundation for a 14-in. pole only, when buried 6 ft. deep in 1 000-lb. per sq. ft. earth, is 25 000 lb. ft. The additional stability required by the addition of double kicking-blocks is 25 000 lb. ft. From Fig. 4F read 25 000 on the middle set of figures on the bottom horizontal scale, and immediately above reach the point of intersection with curve "(*b*) bottom." [Curve (*b*) refers to 6-ft. depth of setting, as per table accompanying Fig. 4F.] Follow horizontally to the left and read 1·5 sq. ft. as the area of the bottom block (excluding the area covered by the pole). Again follow the above value of 25 000 on the middle set of figures on the bottom horizontal scale to the point of intersection with curve "(*b*) top." Follow horizontally to the left and read the area of the top block as 3·1 sq. ft., excluding the area covered by the pole. From the table, the best depth to the centre of the top kicking-block when the pole is buried 6 ft. deep is found to be 2 ft., and to the centre of the bottom block is 5½ ft., which, assuming 10-in. wide blocks, is as near the butt of the pole as practicable.

Fig. 4F has been developed on the assumption that the top and bottom kicking-blocks have the same total effective value of ground reaction, thus leaving the position of the fulcrum point unchanged.

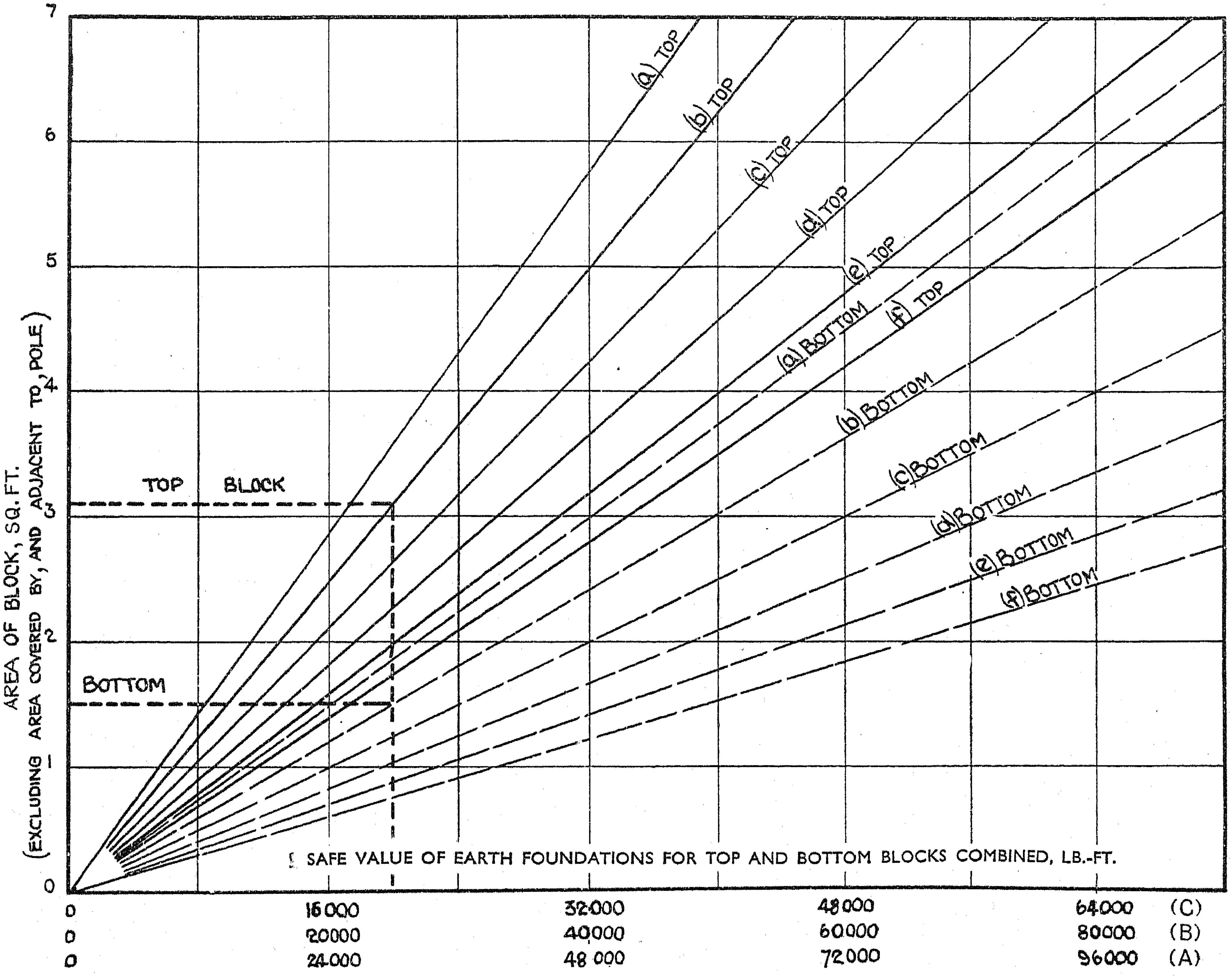


FIG. 4F.—Safe values of earth foundations for combined top and bottom kicking-blocks of various sizes when used on single wood poles set at depths of 5·5–8·0 ft. Factor of safety (based on ultimate ground reaction) = 2·5.

The following values are based on a safe figure of 1 000 lb. per sq. ft. per ft. of depth:—

Total depth of pole in ground	Depth to pivot point	Top block		Bottom block	
		Best depth to centre	Effective value of earth resistance per sq. ft.	Depth to centre of bottom block	Effective value of earth resistance per sq. ft.
ft.	ft.	ft.	lb.	ft.	lb.
(*a*) 5·5	3·666	1·833	3 460	5·0	6 660
(*b*) 6·0	4·000	2·000	4 000	5·5	8 250
(*c*) 6·5	4·333	2·166	4 700	6·0	10 000
(*d*) 7·0	4·666	2·333	5 440	6·5	11 920
(*e*) 7·5	5·000	2·500	6 250	7·0	14 000
(*f*) 8·0	5·333	2·666	7 120	7·5	16 270

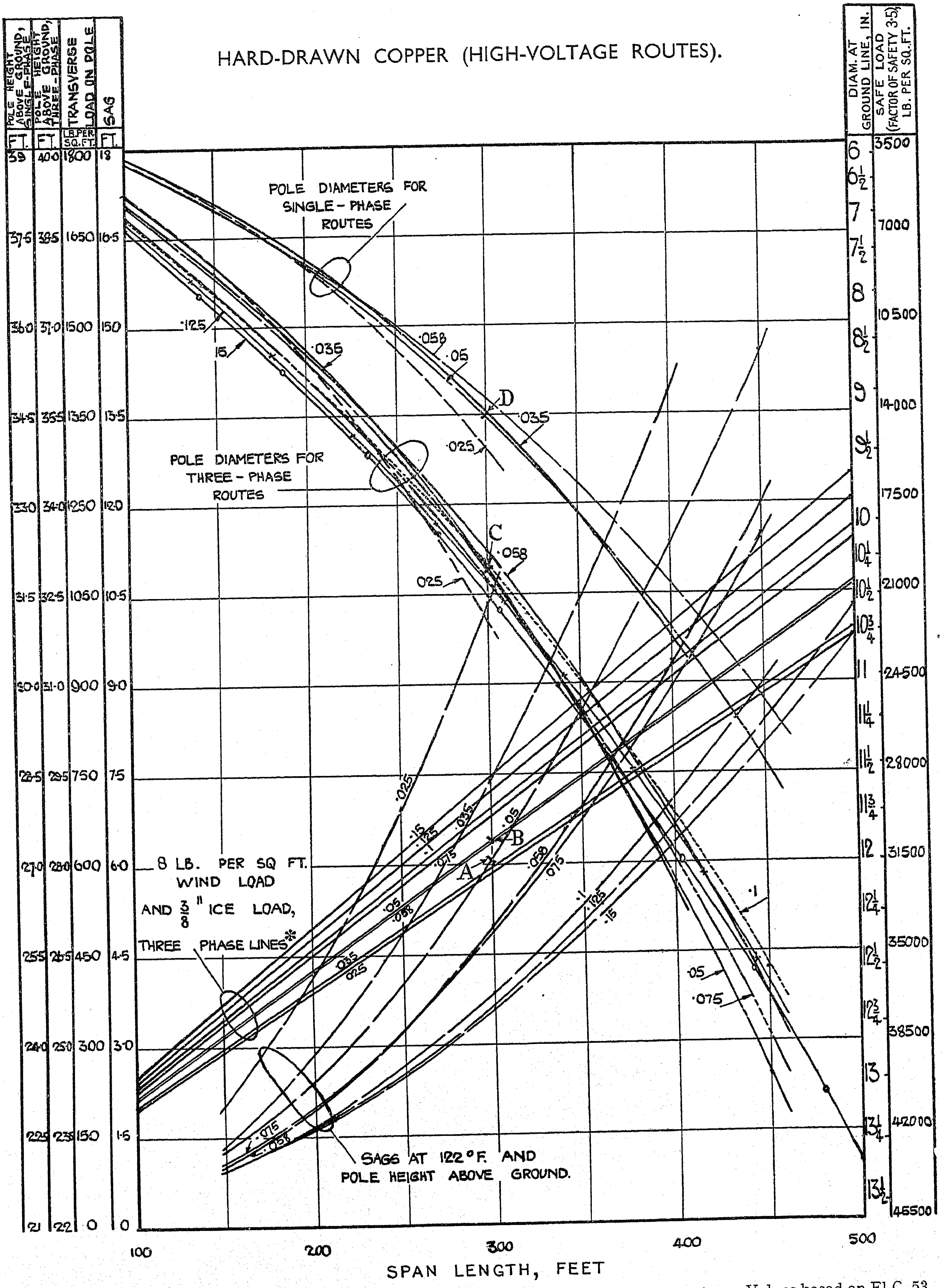


Fig. 5a.—Hard-drawn copper conductors for single-phase and 3-phase high-voltage routes. Values based on El.C. 53, but allowing 1 ft. extra clearance for working margin.

* For single-phase lines take two-thirds of these values.

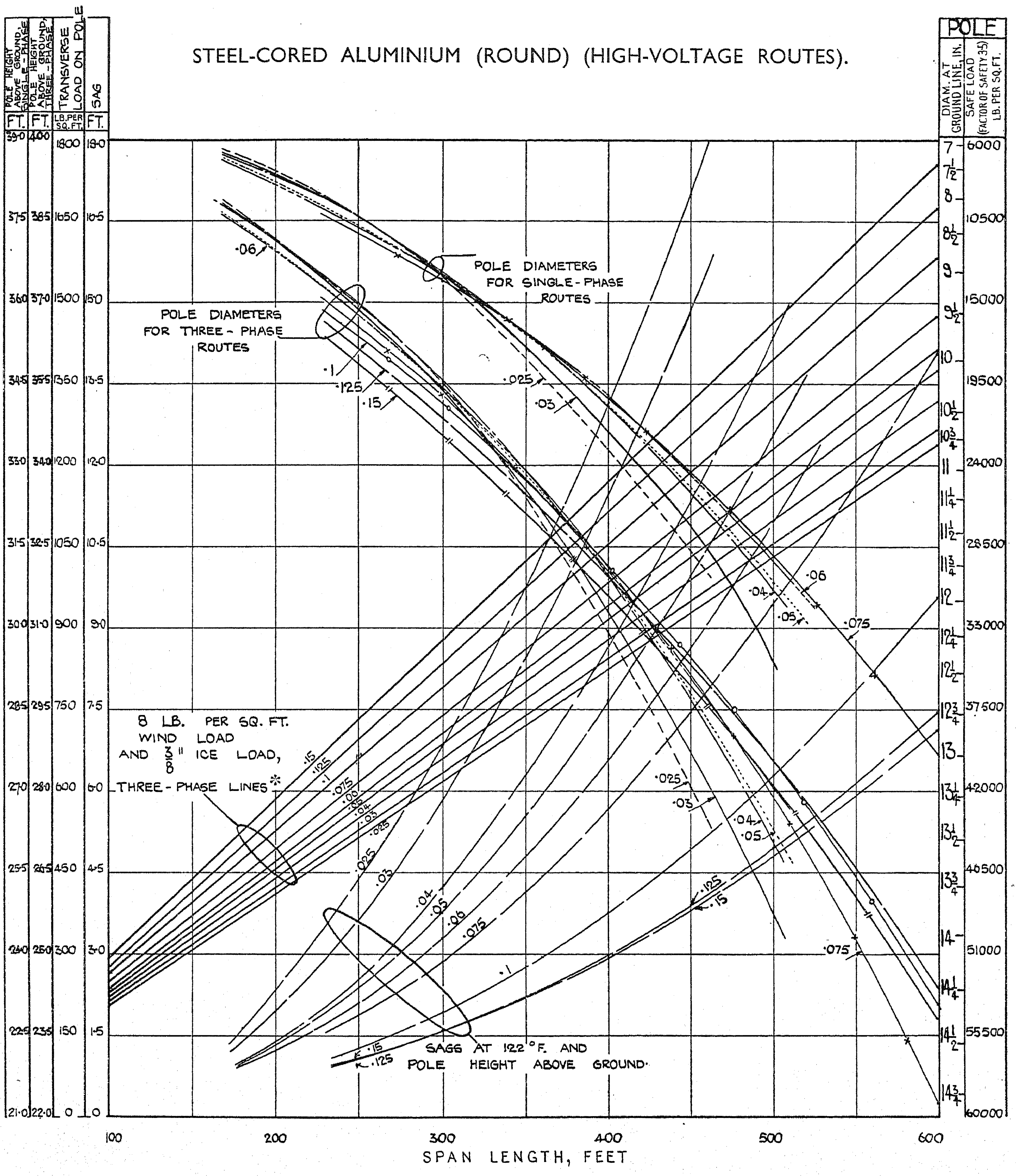


FIG. 5B.—Steel-cored aluminium (round stranded) conductors for single-phase and 3-phase high-voltage routes. Values based on El.C. 53, but allowing 1 ft. extra clearance for working margin.

* For single-phase lines take two-thirds of these values.

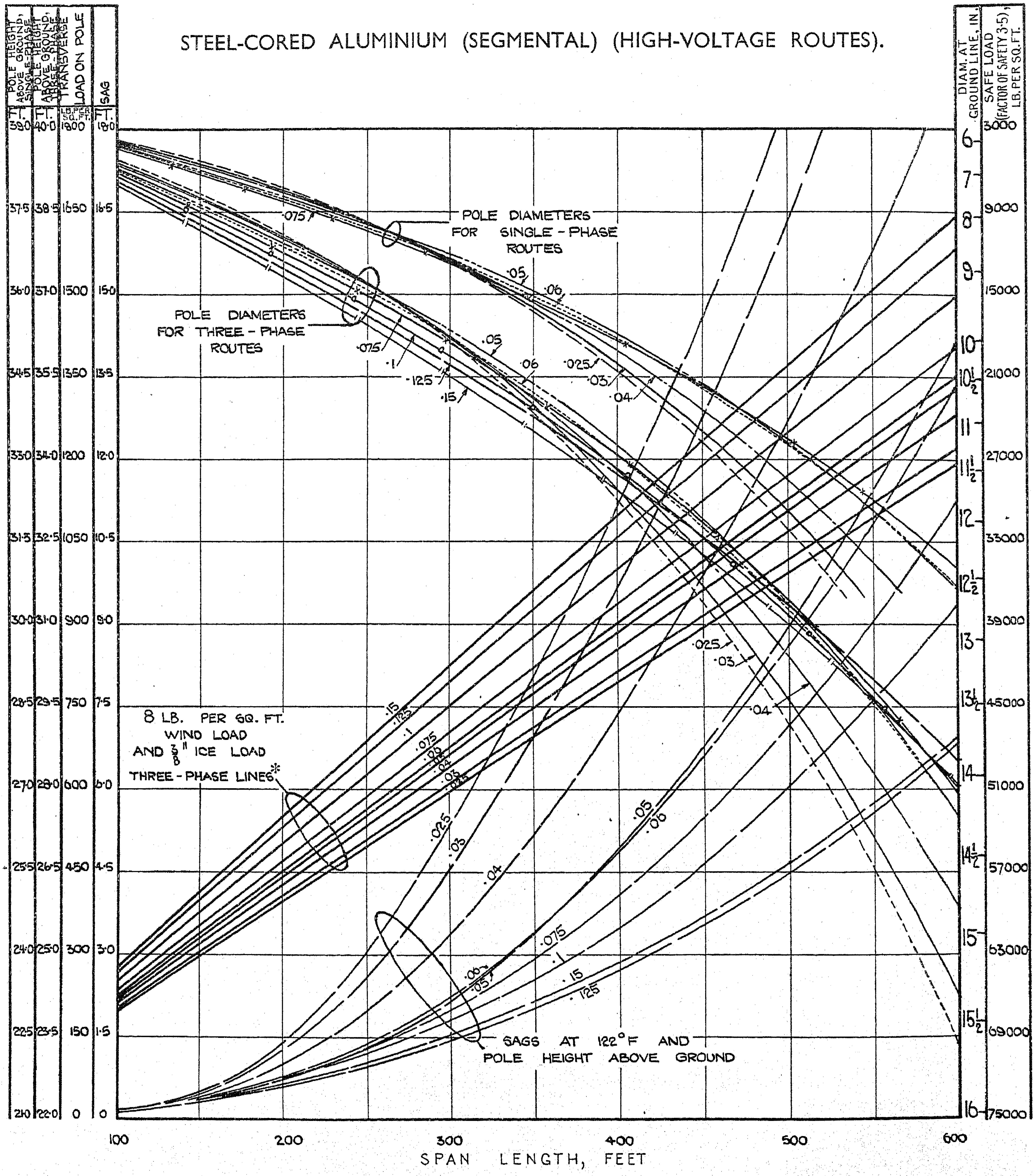


Fig. 5c.—Steel-cored aluminium (segmental) conductors for single-phase and 3-phase high-voltage routes. Values based on El.C. 53, but allowing 1 ft. extra clearance for working margin.

* For single-phase lines take two-thirds of these values.

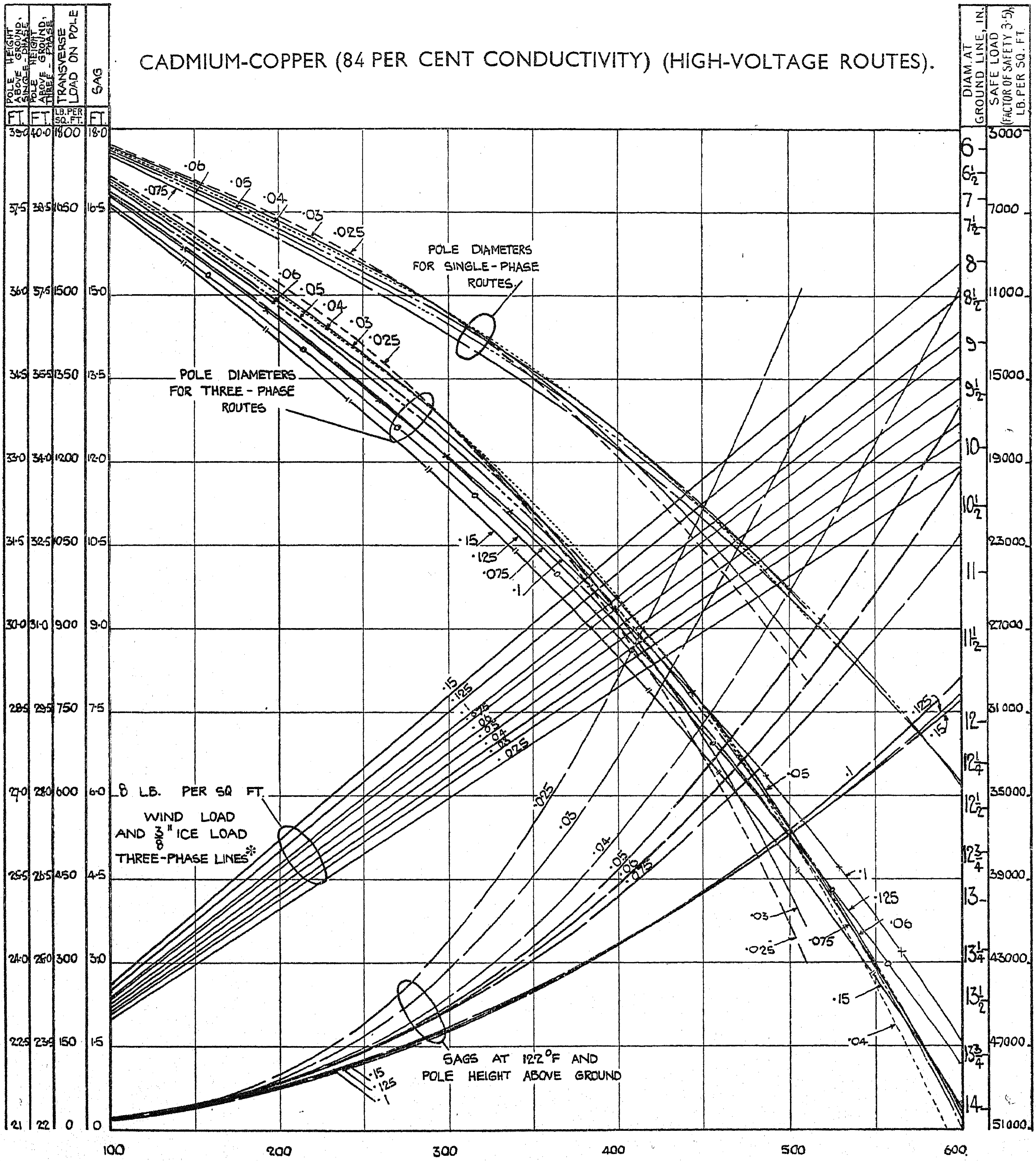


Fig. 5d.—Cadmium-copper (84 per cent conductivity) conductors for single-phase and 3-phase high-voltage routes. Values based on El.C. 53, but allowing 1 ft. extra clearance for working margin.

* For single-phase routes take two-thirds of these values.

(8) Pole Sizes, Etc., Required for High-Voltage 2- and 3-Wire Routes.

Figs. 5A to 5F have been prepared to indicate at a glance: (i) The transverse load on 2- and 3-wire high-tension routes. (ii) The sag at 122° F. (iii) The required pole heights above ground, and the pole diameters at ground line, for 2- and 3-wire routes, for various sizes of conductors on spans from 100 to 600 ft. and of various materials.

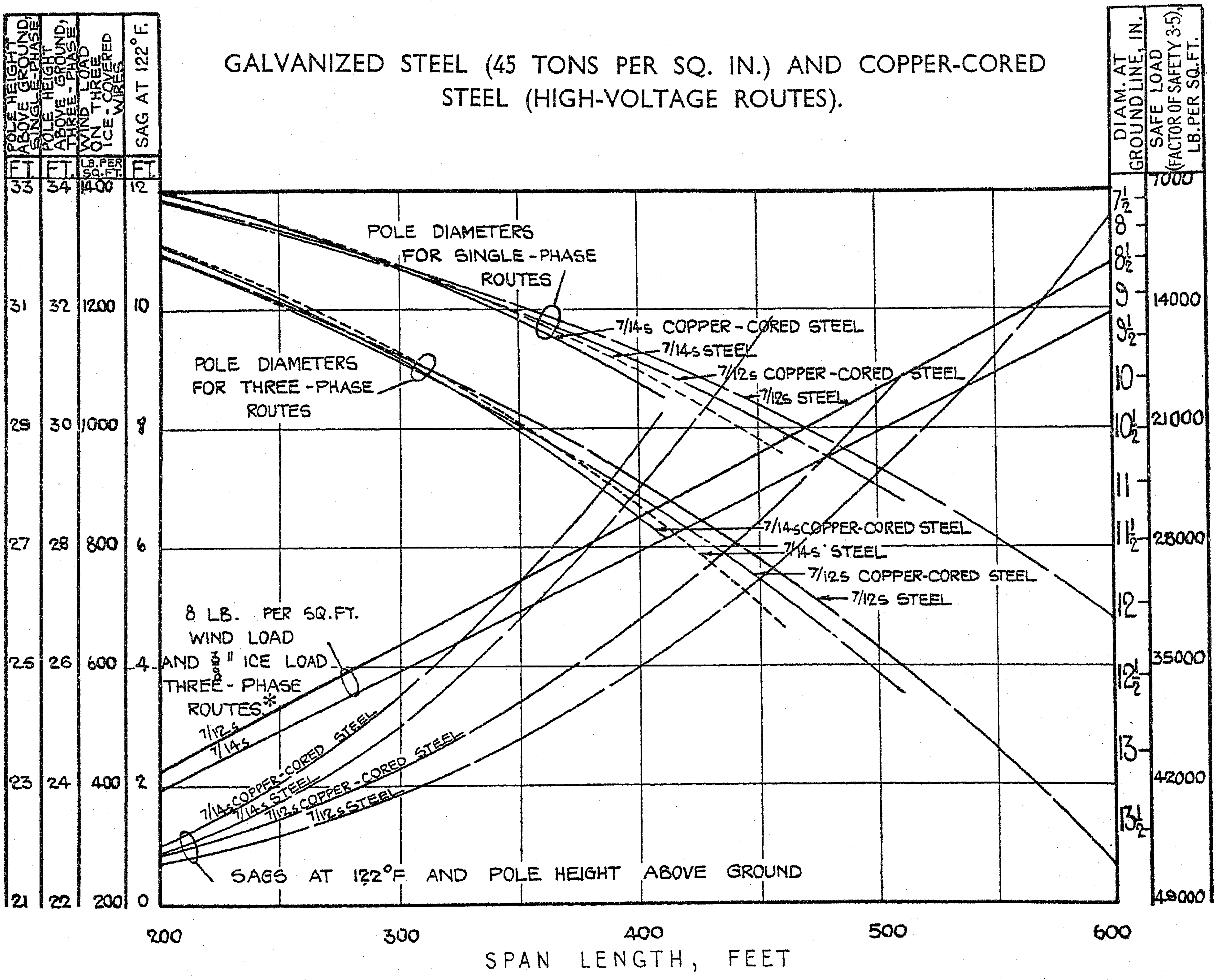


Fig. 5E.—Galvanized-steel conductors and copper-cored steel conductors. Values based on El.C. 53, but allowing 1 ft. extra clearance for working margin.

* For single-phase lines take two-thirds of these values.

Three-Phase Lines.

The graphs for 3-phase lines are based on a pole-top construction similar to those shown in Figs. 6(*a*) to 6(*e*) and in Fig. 6(*f*) for single-phase lines, in all of which the centre of gravity of the transverse load will be approximately at the pole top. These designs enable shorter poles to be used on 3-phase routes. In all cases the minimum ground clearance from the lowest part of the span at 122° F. has been taken as 21 ft., i.e. 20 ft. plus 1 ft. working margin to allow for uneven ground; and otherwise these designs comply with the requirements of El.C. 53 for high-voltage lines.

Example.—To illustrate the use of these graphs, the following brief particulars are given in connection with the one for hard-drawn copper (Fig. 5A), which is typical of the series. The sag for conductors from 0·025 to 0·15 sq. in. on span lengths from 100 to 500 ft. may be read directly in the following way. To find the sag on a 0·05-sq. in. conductor on a 300-ft. span, read 300 ft. on the bottom horizontal scale and follow directly above to the point of intersection (A) with the curve for 0·05 sq. in. Follow to the left horizontally, and in the fourth column read the sag, 6·07 ft. The pole height *above ground* for a 3-wire route will be found horizontally opposite in the second column, viz. 28·07 ft., and for a 2-wire route in the first column, viz. 27·07 ft. The transverse load can be found by following vertically upwards from the 300-ft. value on the bottom scale to the point of intersection (B) with the straight-line diagonal graph for 0·05. Horizontally opposite this point the value 640 lb. may be read in the third left-hand column. For 2-wire routes the transverse load will obviously be two-thirds of this value. The pole diameter at ground line is found by following vertically upwards from the 300-ft. value on the bottom scale to the point of intersection with the graphs for pole diameters for 3-phase routes, running from the top left-hand corner to the bottom right-hand corner of the figure. From the point of intersection (C) with the graph for 0·05 sq. in. follow horizontally to the right and read a value of just over $10\frac{1}{4}$ in.; thus the nearest safe diameter of pole will be $10\frac{1}{2}$ in. It should be noted that the pole diameter is that at the ground line and not at 5 ft. from the butt, so that a suitable allowance should be made, depending on the depth of setting in the ground.

Single-Phase Lines.

For a single-phase route the next series of curves above are used, from which the diameter of the pole at the ground line will be found to be $9\frac{1}{4}$ in., this being the nearest larger size horizontally opposite the point of intersection D.

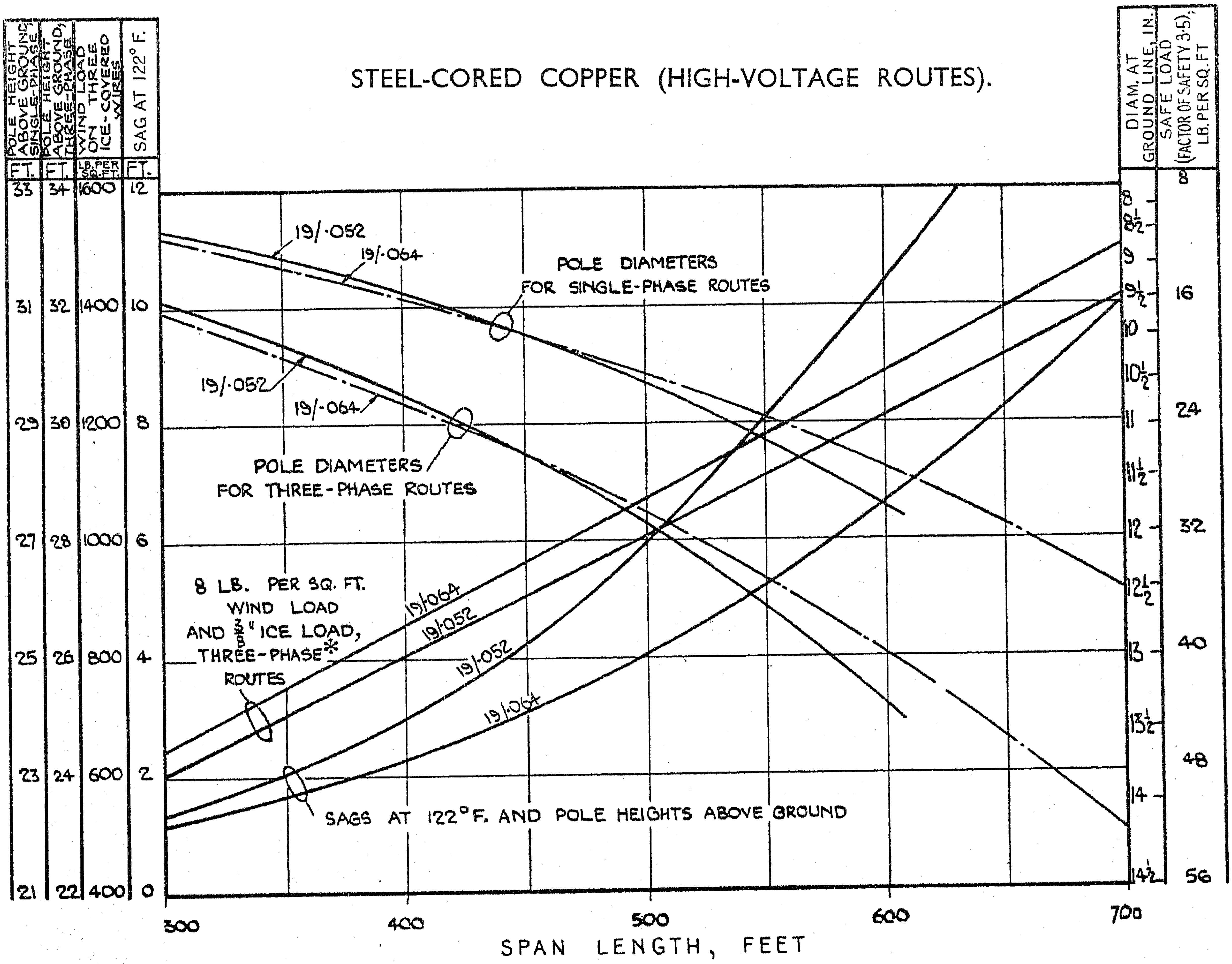


FIG. 5F.—Steel-cored copper conductors. Values based on El.C. 53, but allowing 1 ft. extra clearance for working margin.

* For single-phase lines take two-thirds of these values.

(9) POLE SIZES, ETC., REQUIRED FOR 2-, 3-, 4-, AND 5-WIRE LOW-VOLTAGE ROUTES.

Figs. 7A and 7B indicate the heights above ground and the diameter at ground line (not at 5 ft. from the butt) for poles for 2-, 3-, 4-, and 5-wire 0·1-sq. in. and 0·058-sq. in. routes. In the case of 5-wire routes the fifth wire is a switch wire for control of public lighting, and has a cross-sectional area of 0·0221 sq. in. (7/·064). The basis for the design is a sag of 3 ft. on 180-ft. spans at 122° F., and transverse loading as set out in Regulations El.C. 53. These graphs should be used in conjunction with the stay details given in Table 2.

As an alternative, for schemes where there are numerous bends and terminals, Figs. 7C and 7D have been prepared. These give similar details to Figs. 6A and 6B, but are based on a sag of 3 ft. 6 in. at 122° F. on 180-ft. spans, thus reducing the stresses in angle and terminal stays as shown in Table 3.

Figs. 7A to 7D are based on the pole-top arrangements shown in Fig. 8.

(10) Selection of Conductors and Span Lengths.

Low-voltage Lines.

As already stated, with copper at its present price this is the only material which should be seriously considered for low-voltage lines. Span lengths usually range from 120 ft. to 180 ft., 150 ft. being a good average. The exact length is largely determined by the frequency of service tappings and the number of street junctions. For long branch service lines across fields where no properties have to be supplied en route, spans up to 240 ft. are recommended.

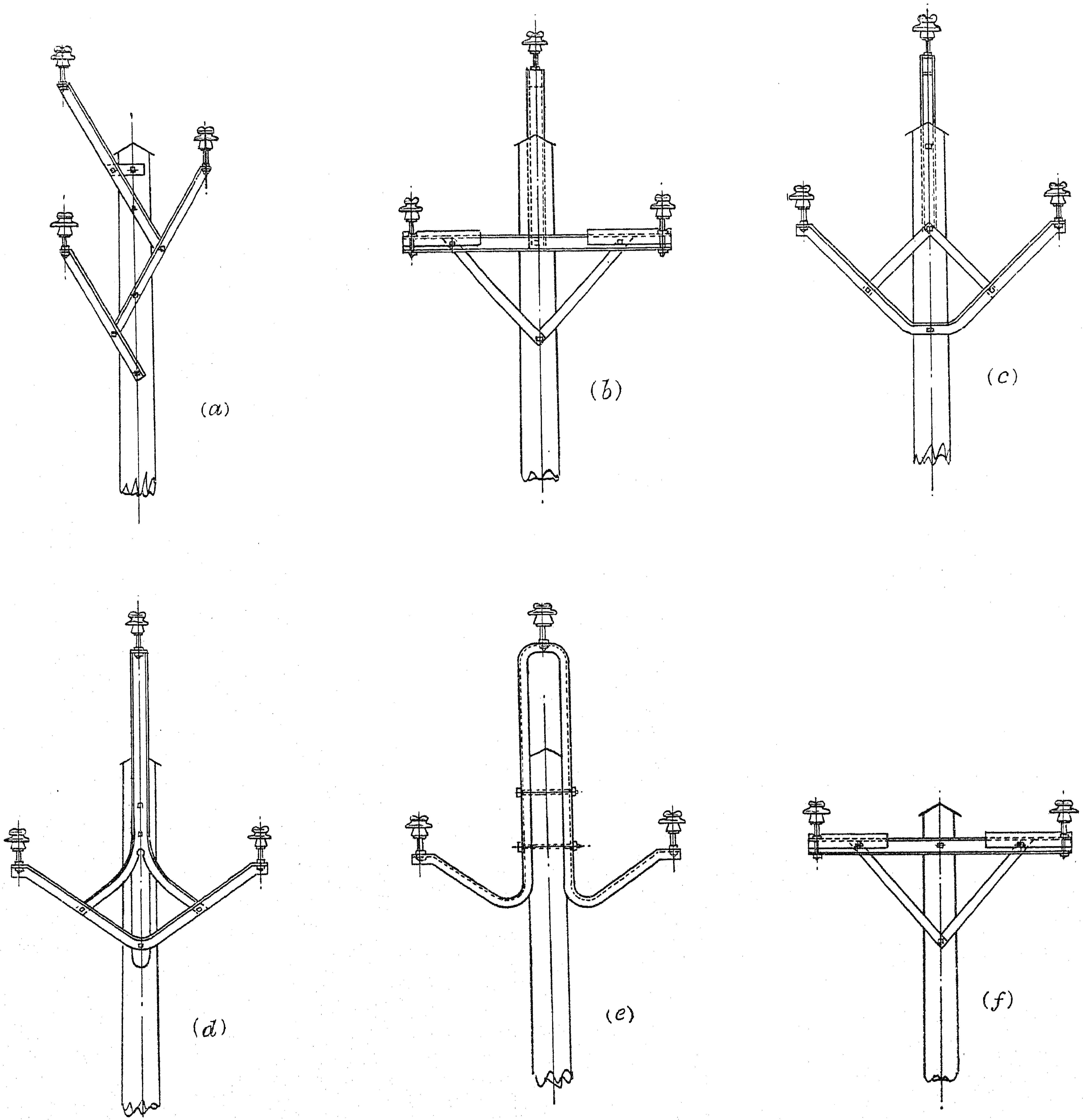


Fig. 6.—Typical pole-tops for high-voltage lines. Scale $\frac{1}{3}$ in. = 1 foot.

High-voltage Lines.

The selection of the conductor material and span length for high-voltage rural lines involves many variables, the chief of which are the kilowatt-miles to be transmitted, the nature of the country to be traversed, and the basic price of the conductor material.

For small branch lines, particularly in flat country where long spans can be used, galvanized steel offers the cheapest line. A 3-phase 11 000-volt galvanized-steel 7/12 S.W.G. line with conductors at 4-ft. spacing will transmit 300 kW at 0·85 power factor

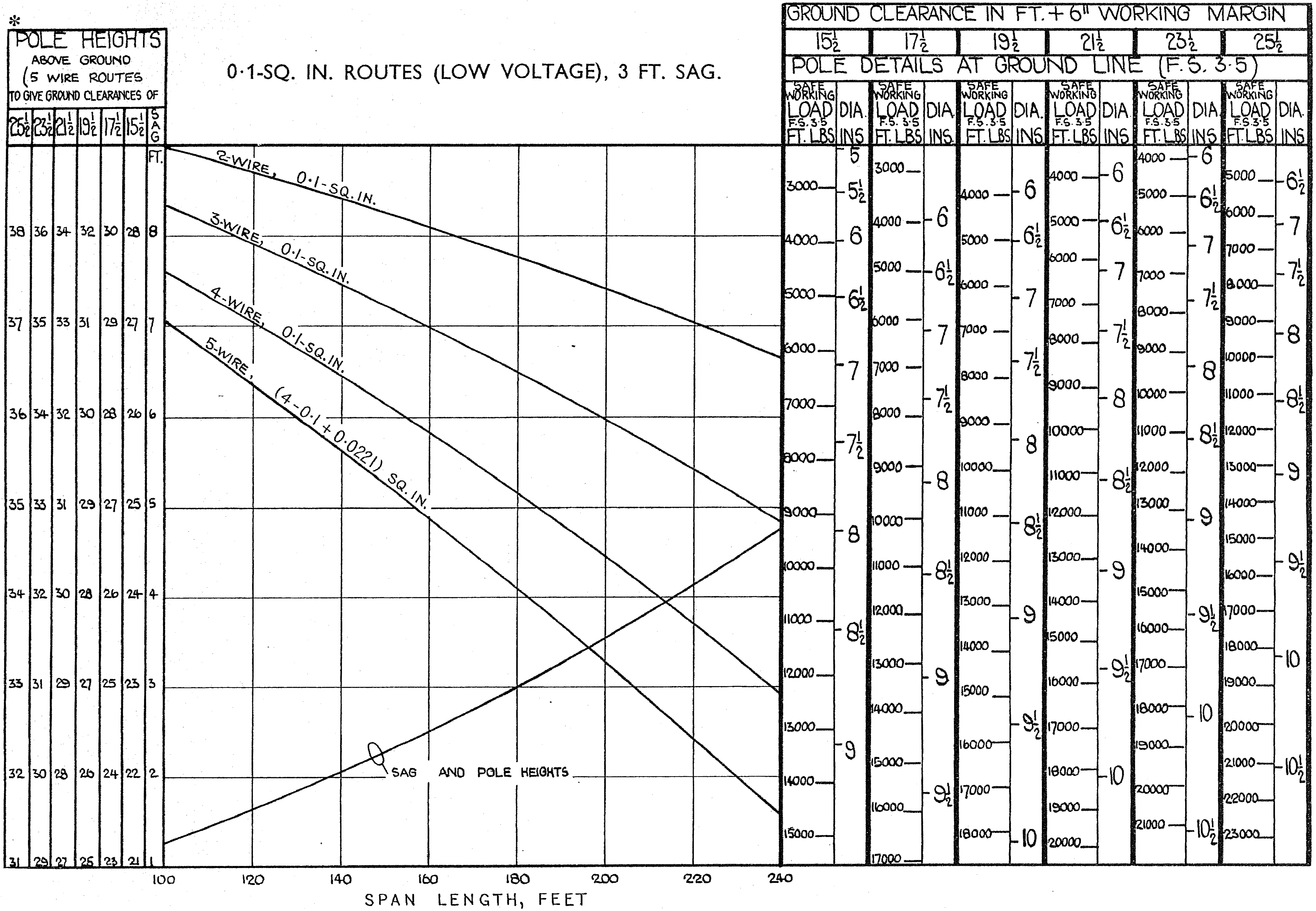


FIG. 7A.—Pole sizes for medium-voltage lines equipped with 0·1-sq. in. (7/·136 in.) hard-drawn copper conductors. Values based on 3 ft. sag on 180-ft. span at 122° F., wind and ice loading as in El.C. 53, and pole heights giving 6 in. extra on sag for working margin.

* Deduct 1 ft. per conductor from pole heights for routes with fewer conductors.

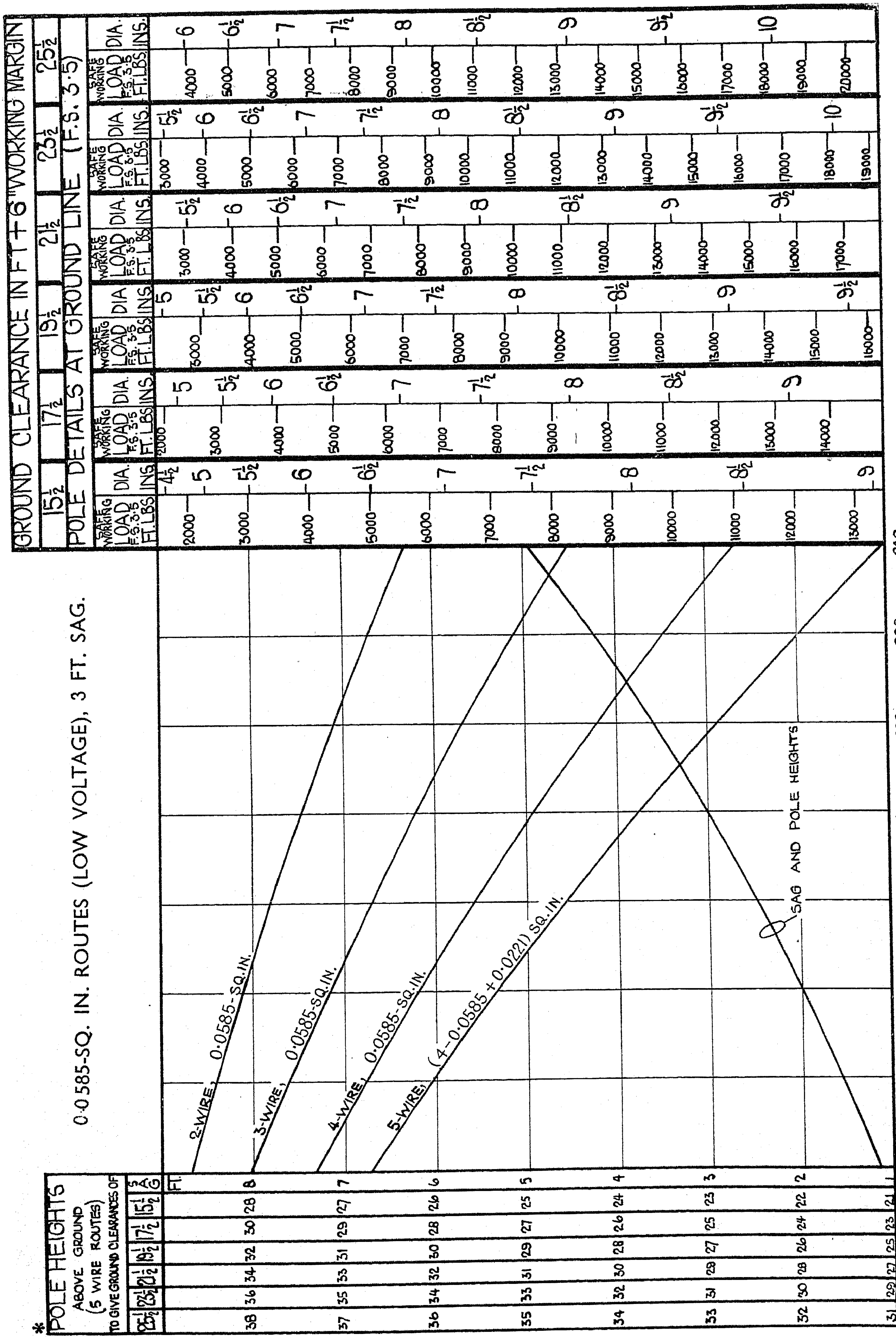


FIG. 7B.—Pole sizes for medium-voltage lines equipped with 0·0585-sq. in. (7/·104 in.) hard-drawn copper conductors. Values based on 3 ft. sag on 180-ft. span at 122° F., wind and ice loading as in El.C. 53, and pole heights giving 6 in. extra on sag for working margin.

* Deduct 1 ft. per conductor from pole heights for routes with fewer conductors.

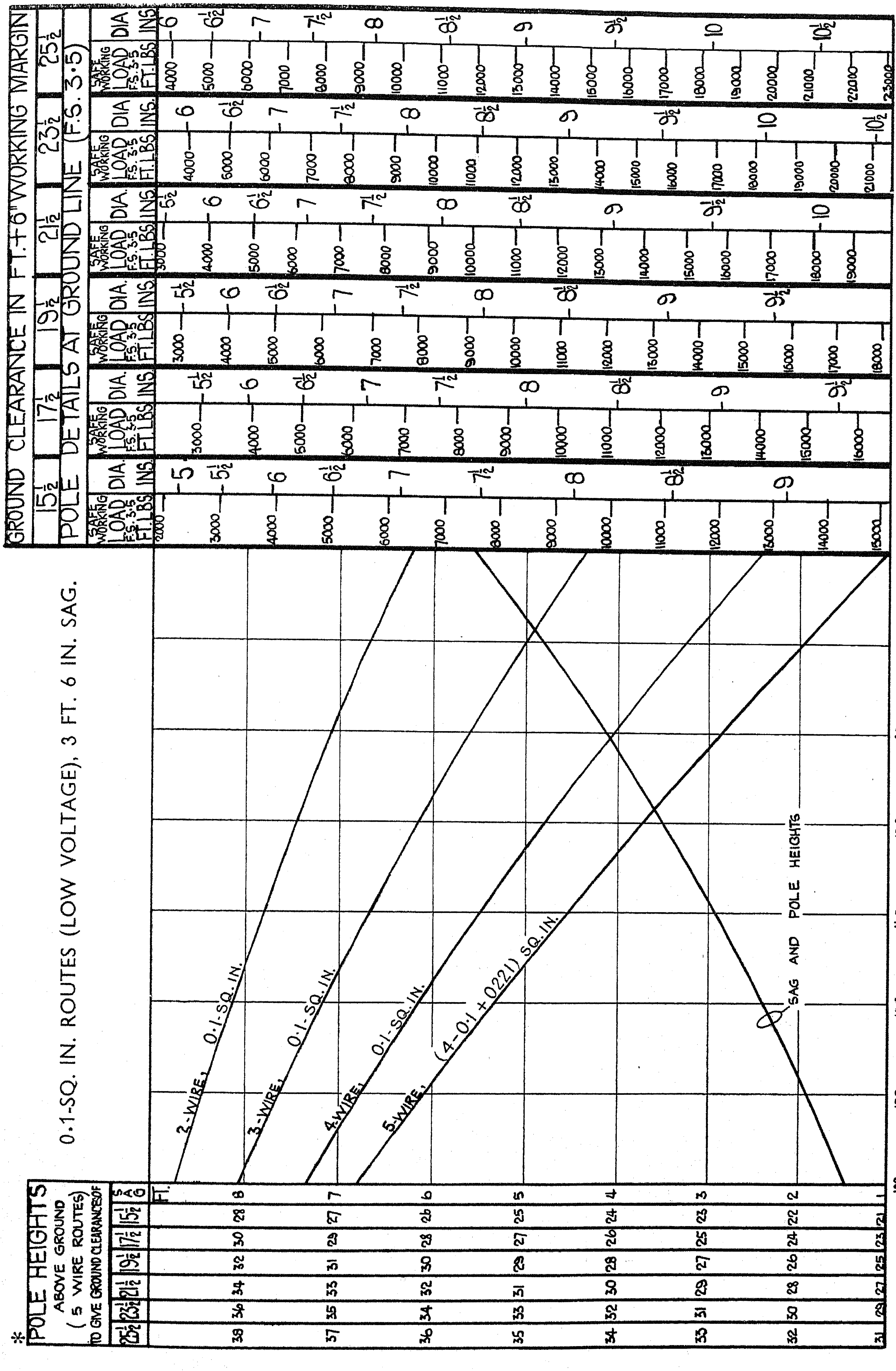


FIG. 7C.—Pole sizes for medium-voltage lines equipped with 0·1-sq. in. (7/·136 in.) hard-drawn copper conductors. Values based on 3 ft. 6 in. sag on 180-ft. span at 122° F., wind and ice loading as in El.C. 53, and pole heights giving 6 in. extra on sag for working margin.

* Deduct 1 ft. per conductor from pole heights for routes with fewer conductors.

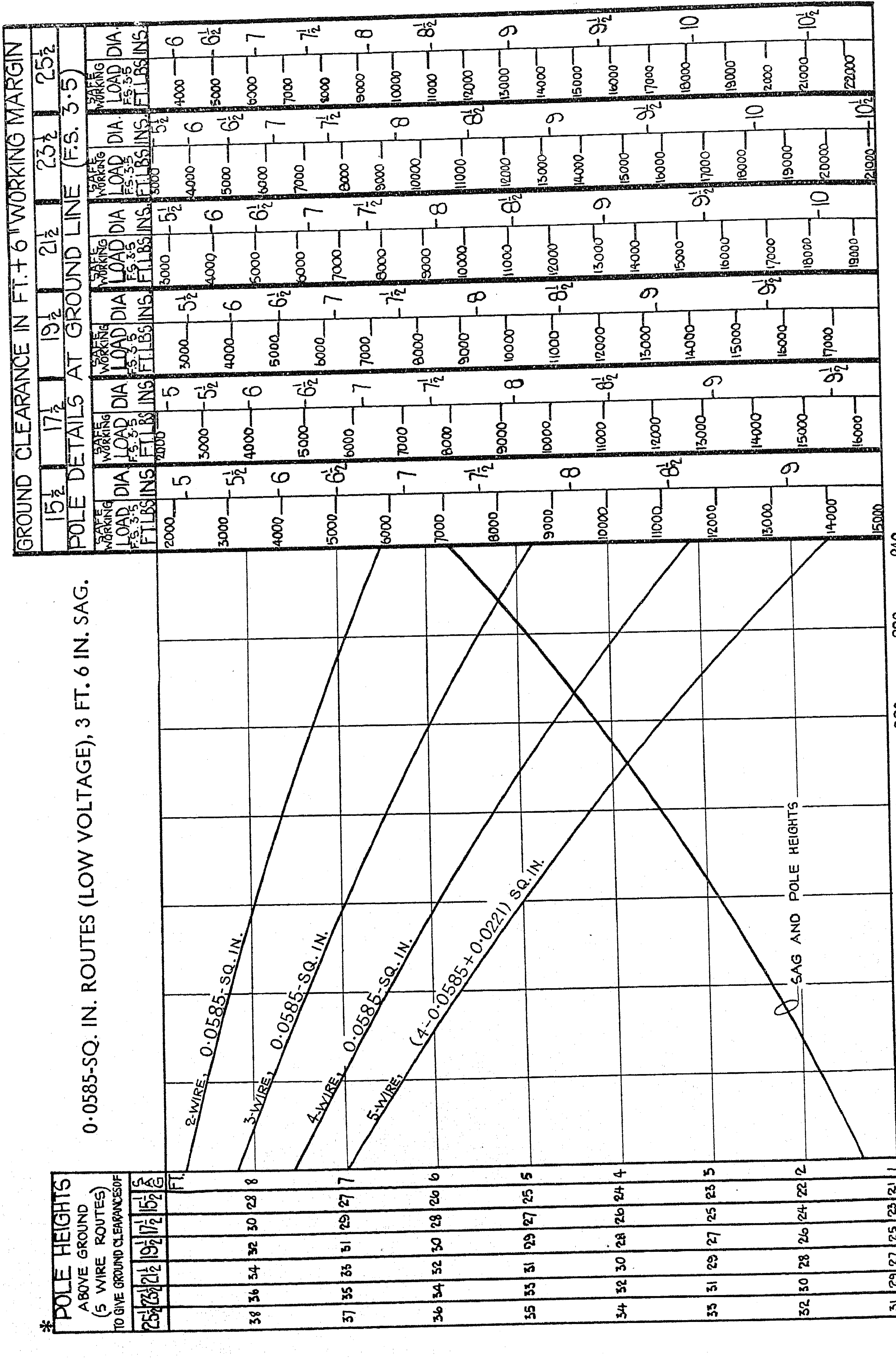


FIG. 7D.—Pole sizes for medium-voltage lines equipped with 0·0585-sq. in. (7/·104 in.) hard-drawn copper conductors. Values based on 3 ft. 6 in. sag on 180-ft. span at 122° F., wind and ice loading as in El.C. 53, and pole heights giving 6 in. extra on sag for working margin.

* Deduct 1 ft. per conductor from pole heights for routes with fewer conductors.

3 miles with a voltage-drop of approximately 5 per cent.

Tables 8 and 8A have been prepared from Figs. 5A to 5F, to show the span length and cost per mile for 3-phase 11 000-volt lines using different classes and sizes of conductors. The total costs per mile given in Table 8A are based on span lengths which involve a sag of 9 ft. at 122° F., for straight lengths of route in fairly flat country, and include only the following: (*a*) Price per mile for poles, including distribution on site, ironwork, insulators, earthing, dressing, and erection. (*b*) Price per mile for conductors. (*c*) Cost of wayleaves capitalized at £1 10s. per pole. (*d*) Basic price of copper electrolytic wire bars £33 5s. per ton, and of aluminium £95 per ton. A maximum sag of 9 ft. has been selected as a figure which has proved economical in practice for wood-pole lines for high-voltage rural distribution. It should be noted that the total price per mile does not include the erection of the conductors, obtaining of wayleaves, special crossings, or angle or terminal poles, as these factors are not considered necessary for the present comparison.

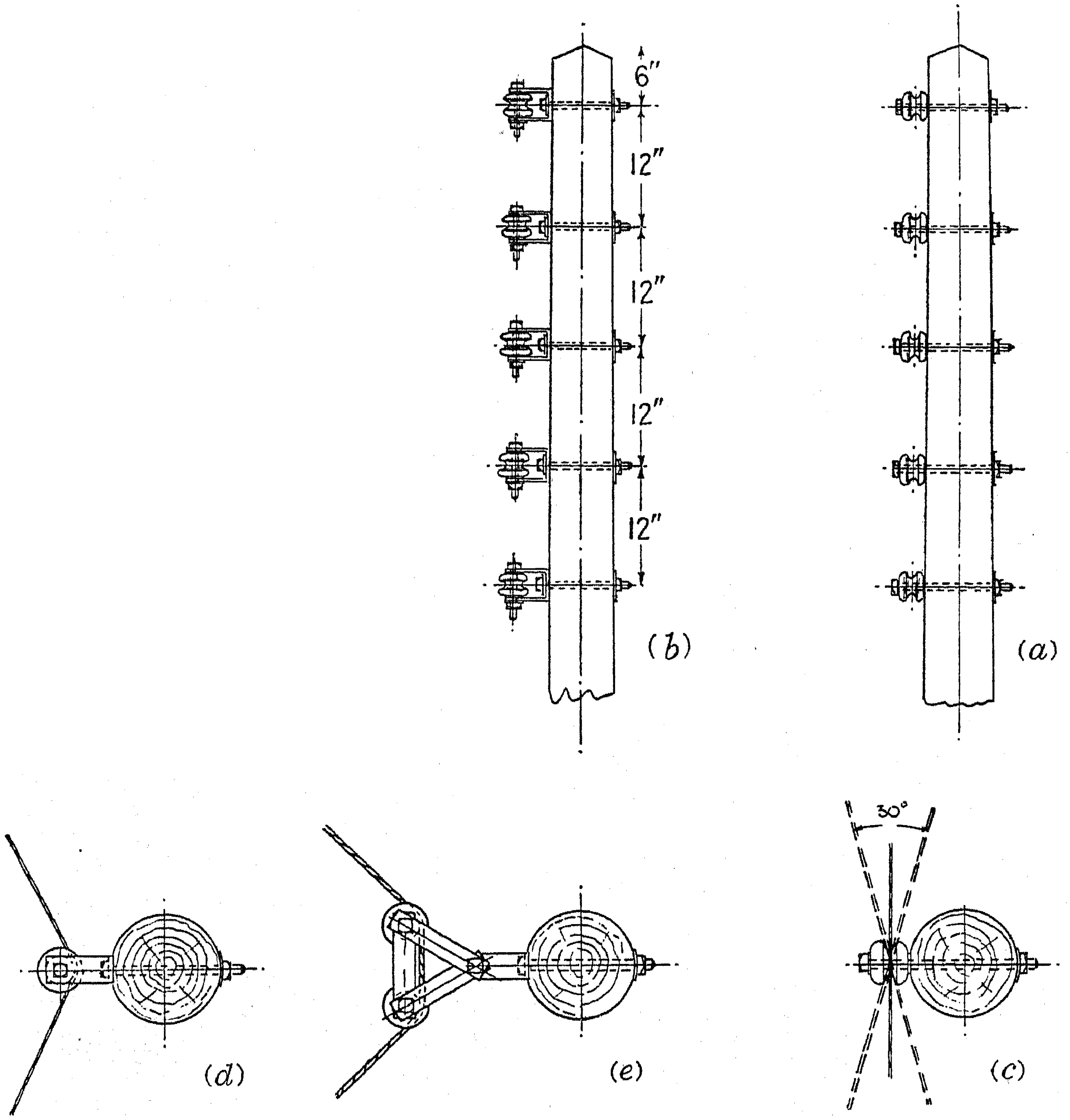


FIG. 8.—Typical pole-tops for low-voltage and medium-voltage lines.
Scales: $\frac{1}{2}$ in. = 1 ft. (*a*, *b*), $\frac{3}{4}$ in. = 1 ft. (*c*, *d*, *e*).

(*a*), (*b*) Straight-line and slight-angle pole.
(*c*) Pole for straight lines and for angles up to 15° deflection.
(*d*) Angle pole (15°–30° deflection).
(*e*) Angle pole (over 30° deflection).

From the tables it is apparent that, excluding galvanized steel, copper-cored steel and then steel-cored copper provide the cheapest lines; but the author doubts whether sufficient experience has yet been obtained of the electrochemical action which may arise as a result of a number of years' exposure to the weather, to recommend the use of this type of conductor at the present stage.

Steel-cored aluminium became very popular some 3 to 4 years ago, at the time of the construction of the 132 000-volt grid lines for the Central Electricity Board. It is still no doubt the best for use on the very long-span construction associated with extra-high-voltage lines for the long-distance transmission of large amounts of power. The extra tensile strength and relative lightness of the conductors enables longer spans to be used. Further, although the increased diameter of the conductor involves greater wind and ice loading it definitely raises the critical corona-voltage limits of the lines, and this, in the case of extra-high-voltage lines, more than compensates for the increased wind and ice loading. This increased diameter of steel-cored aluminium conductors on such lines avoids the necessity for increased spacing between conductors, or the use of expensive specially-constructed hollow copper conductors. In addition to the above,

TABLE 8.

Approximate Span Length involving a Sag of 9 ft. at 122° F. for various Sizes and Classes of Conductors ; also Pole Size required for 3-phase Routes.

Poles of 12-in. diameter and larger, set 7 ft. deep. Ground clearance, 20 ft. + 1 ft. working margin to allow for uneven ground.

Copper equivalent sectional area, sq. in.	Galvanized steel (45 tons per sq. in.)			Copper-cored steel			Steel-cored copper			Hard-drawn copper			Cadmium copper			Steel-cored aluminium (round stranded)			Steel-cored aluminium (segmental)		
	*(a)**	*(b)**	*(c)**	*(a)*	*(b)*	*(c)*	*(a)*	*(b)*	*(c)*	*(a)*	*(b)*	*(c)*	*(a)*	*(b)*	*(c)*	*(a)*	*(b)*	*(c)*	*(a)*	*(b)*	*(c)*
0·0036	7/·080	440	38×12¼																		
0·0062	7/·104	545	38×13¼																		
0·0082				7/·080	420	37×11¾															
0·0138				7/·104	510	38×13															
0·025							19/·052	570	38×13¼	3/·104	280	37×10½	3/·113	415	37×11¾	7/·093	335	37×11	1/·079	365	37×11½
0·03							—	—	—	—	—	—	3/·124	445	38×12¼	7/·102	360	37×11½	1/·087	390	38×12
0·035							—	—	—	7/·08	325	37×11	—	—	—	—	—	—	—	—	—
0·04							19/·064	670	38×14	—	—	—	3/·144	485	38×12¾	7/·118	405	38×12¼	1/·102	430	38×12¼
0·05							7/·103	515	38×13	3/·147	360	37×11½	3/·161	515	38×13¼	7/·132	430	38×12½	7/·044	500	38×13
0·06										7/·104	395	38×12	3/·176	535	38×13½	7/·144	460	38×13	1/·125	510	38×13
0·075										3/·180	400	38×12¼	3/·197	555	38×13¾	7/·161	490	38×13½	1/·140	550	38×13¾
0·1										7/·136	450	38×12¾	7/·148	625	38×14¼	7/·173 +7/·076	585	38×14½	7/·054	590	38×14

* *(a)* = Stranding and wire diameter. *(b)* = Approx. span length (ft.) for 9ft. sag. *(c)* = Pole size required: height (ft.) and diameter (in.) at 5 ft. from butt.

TABLE 8A.

Approximate Cost, £ per Mile, for Poles fully equipped, and Conductors for 3-phase Routes, using various Sizes and Classes of Conductors. Maximum Sag at 122° F. = 9 ft. Cost of Erection of Conductors excluded.

Copper equivalent sectional area, sq. in.	Galvanized steel (45 tons)				Copper-cored steel				Steel-cored copper				Hard-drawn copper				Cadmium copper				Steel-cored aluminium (round stranded)				Steel-cored aluminium (segmental)			
	*(a)**	*(b)**	*(c)**	*(d)**	*(a)*	*(b)*	*(c)*	*(d)*	*(a)*	*(b)*	*(c)*	*(d)*	*(a)*	*(b)*	*(c)*	*(d)*	*(a)*	*(b)*	*(c)*	*(d)*	*(a)*	*(b)*	*(c)*	*(d)*	*(a)*	*(b)*	*(c)*	*(d)*
0·0036	12	142	21·5	163·5																								
0·0062	9·7	126	32·7	158·7																								
0·0082					12·6	143·75	27	170·75																				
0·0138					10·35	132	42	174																				
0·025									9·25	120·2	58·4	178·6	19·9	193·3	40·9	234·2	12·7	145	52·7	197·7	15·75	165·4	44·4	209·8	14·5	160·2	51·7	211·9
0·03									—	—	—	—	—	—	—	—	11·9	141	62·6	203·6	14·7	162·3	53·5	215·8	13·5	154·9	61	215·9
0·035									—	—	—	—	16·25	170·6	55·5	226·1	—	—	—	—	—	—	—	—	—	—	—	—
0·04									7·9	107·8	81·9	189·7	—	—	—	—	10·9	136·3	82·5	218·8	13	154	72·6	226·6	12·3	145·7	79·5	225·2
0·05									10·25	130·9	81·3	212·2	14·7	162·3	79·2	241·5	10·25	133·3	103·5	236·8	12·3	149·9	89·2	239·1	10·55	134·5	99	233·5
0·06													13·4	153·8	95·1	248·9	9·9	130·7	122·7	253·4	11·5	149·5	101·4	250·9	10·35	131·9	120	251·9
0·075													13·2	156·5	118·8	275·3	9·5	127·2	151·5	278·7	10·8	142·5	132	274·5	9·6	128·6	148·5	277·1
0·1													11·72	146·6	157·8	304·4	8·45	118·5	202·8	321·3	9	128·3	174·7	303	8·95	122·2	196·5	318·7

* *(a)* = Number of poles per mile. *(b)* = Cost (£) of poles erected and equipped. *(c)* = Cost (£ per mile) of three conductors. *(d)* Total cost (£).

copper some 3 to 4 years ago was approximately 3 times as costly as it is to-day, with the result that steel-cored aluminium conductors were used extensively for many high-voltage lines operating at 6 600 and 11 000 volts, even on medium span lengths.

With metals at the prices referred to in connection with Table 8A, however, copper appears to result in the cheapest line where relatively short-span construction is necessary, as in broken or uneven country, except in the case of the very small conductors of 0·025 sq. in. and less, the minimum permissible size for copper being 0·0201 sq. in.

For the medium-span construction (450–600 ft.) usually associated with rural distribution lines in fairly flat country, the author recommends cadmium copper, particularly for 33 000-volt lines (where the cost of insulators per pole is higher than for the 11 000-volt lines on which the table is based) and for conductors up to 0·075 sq. in. cross-section.

It should be stressed that, contrary to generally-accepted ideas, medium-span construction (450–600 ft.) is safer both mechanically and electrically than short-span construction, where both are designed to comply with Regulations El.C. 53.

Part II. Practical Details of Construction.

(1) ATTACHMENT OF KICKING BLOCKS.

The usual method of attaching kicking blocks to poles is shown in Fig. 9(*a*). This method cannot be too strongly condemned, particularly in the case of the upper block (where two kicking blocks are used), for the following reasons. (i) It necessitates drilling a comparatively large hole through the pole at a point subject to almost the greatest stress (often 20 000 to 30 000 lb.). (ii) Unless the block is bolted to the pole before erection, considerable excavating is required to render it possible to place the bolt in position. (iii) It allows water to penetrate to the very heart of the pole and thus hastens decay at a most vulnerable point. The water entering in this manner is absorbed along the end grain of the timber very much more easily than water entering from the outside.

The arrangement shown in Fig. 9(*b*) is suggested as being simple, inexpensive, and effective. The 3-in. wide flat galvanized saddle prevents damage to the outer fibres of the timber when the clamp is tightened up. Further, this arrangement enables the top block to be fixed in position after the earth around the pole has been filled in to the level of the under-side of the block. The hole to accommodate the top block can then be cut to depth and size in the exact position required, and the block dropped into position with the clamp loosely attached. The method ensures that the whole of one side of the top block, and nearly half of the opposite side, are acting against undisturbed earth, as shown by the shaded portion in Fig. 9(*c*).

(2) METHOD OF NEGOTIATING ANGLES ON LOW-VOLTAGE ROUTES.

When heavy low-voltage conductors (0·1 sq. in. or over) are being erected on routes including sharp corners it is often difficult to ensure that the conductors will be sufficiently flexible to negotiate the bends without undue friction. In this connection the arrangement shown in Fig. 8(*e*) is most useful, particularly if the bolts securing the insulators are left slack until the lines have been finally sagged. Duplicate reel insulators are fitted on each sharp angle, in a braced frame consisting of standard shackle straps, and in this way the individual bends on the conductor are halved. Using this arrangement it has been found possible to pull up long lengths of stranded conductors of sizes up to 0·1 sq. in. on routes which include a number of 90° angles, and thus avoid the cost and unsightliness of terminating at each sharp angle.

(3) DEVICE FOR FACILITATING FIXING OF CHAFER TAPES ON CONDUCTORS AT ANGLE POLES ON HIGH-VOLTAGE ROUTES.

Unless proper provision is made at the outset to enable workmen to carry out necessary operations with reasonable ease and safety, there is a great risk of detail work being neglected. The fitting of chafer tapes on conductors, particularly at angle poles on high-voltage lines, is a typical case. High-voltage conductors are almost invariably strained to a factor of safety of 2, and the stresses involved at even small angle positions are heavy, with the result that difficulty is often experienced in withdrawing the conductors from pin-type insulators to allow the chafer tape to be bound on.

To enable this to be done with comparative ease, the device shown in Fig. 10 was designed and brought into use. The lever is arranged to pivot on the hinge piece A, which is temporarily fixed to the insulator spindle by means of the usual lock-nut. The clips B are made adjustable so that the lever may be used for lines having spindles of different lengths. The lever is first fixed in position by the hinge piece A, and the clips B are secured immediately under the conductor to prevent the latter sliding down the vertical lever arm when the conductor is pulled clear of the groove in the insulator. This can be done by pulling on the rope C at the outer end of the lever arm. For large conductors or on heavy angles it may be necessary to use a light set of rope blocks to obtain the necessary pull at the end of the lever.

(4) EQUIPMENT OF DERRICK POLE FOR ERECTION OF HEAVY "H" POLES.

"H" poles, where used on rural distribution schemes, generally occur at angle, section, or transformer poles, and are usually stayed. In such cases it is advisable to fix the stay rods in position before erecting the "H" poles. A large erection gang is not usual for dealing with the single-pole construction, and the erection of the "H" poles is often rather difficult with a small gang, owing to the weight involved.

To avoid having to employ a larger gang to deal with the few "H" poles usually encountered, the author has found the use of a light derrick pole equipped as shown in Fig. 11 to be most useful. The rope blocks are attached to a short length of 3½ in. × 2 in. channel iron bolted near the derrick pole top, one block to each flange, so that the down pulling ropes clear each other. By arranging two jockey pulleys diagonally opposite each

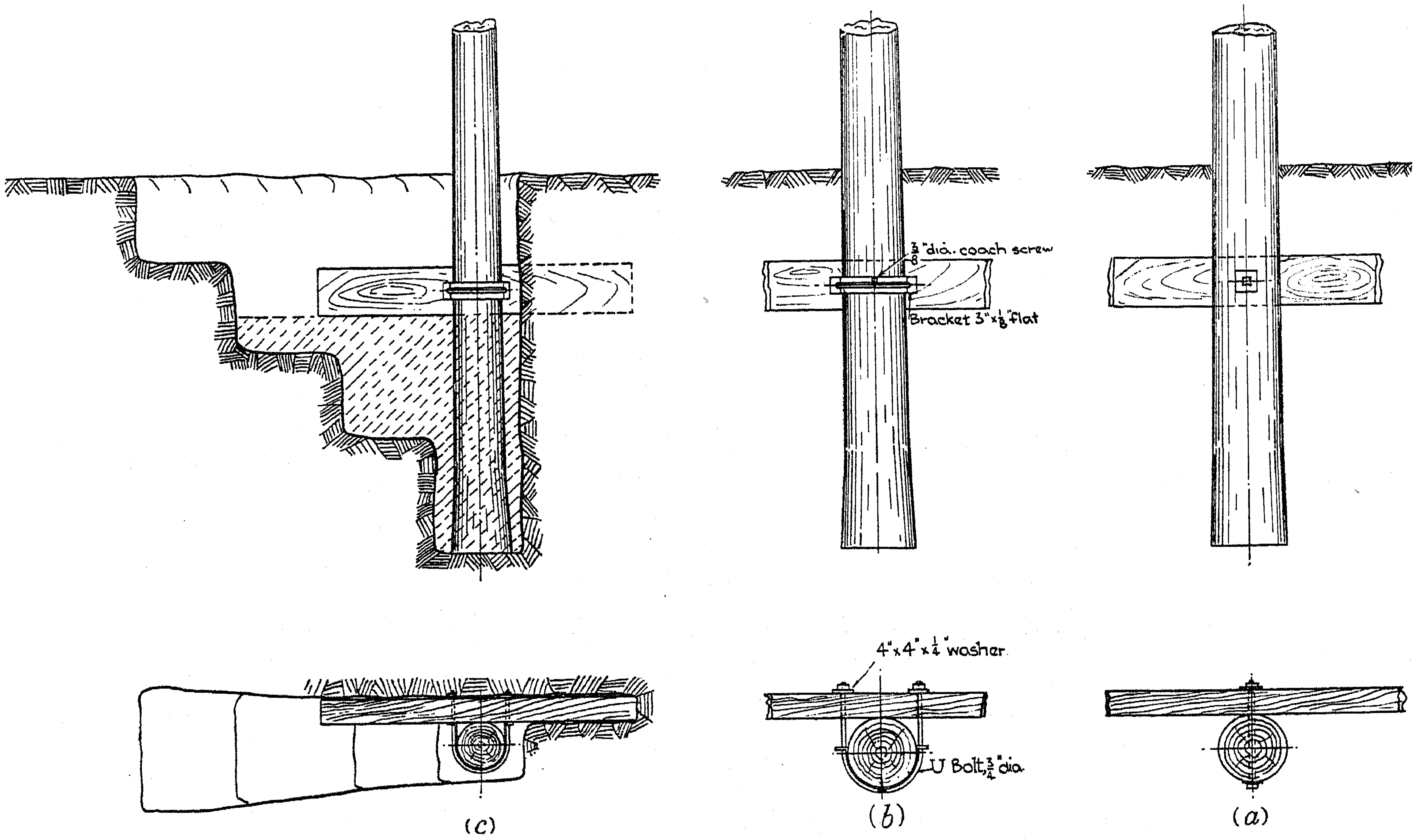


FIG. 9.

(*a*) Old method of attaching kicking-block to pole.
(*b*) Suggested method of attaching kicking-block to pole.

(*c*) Shows large area of undisturbed earth (cross-shaded) which can be fully utilized by excavating hole for kicking-block after pole has been erected.

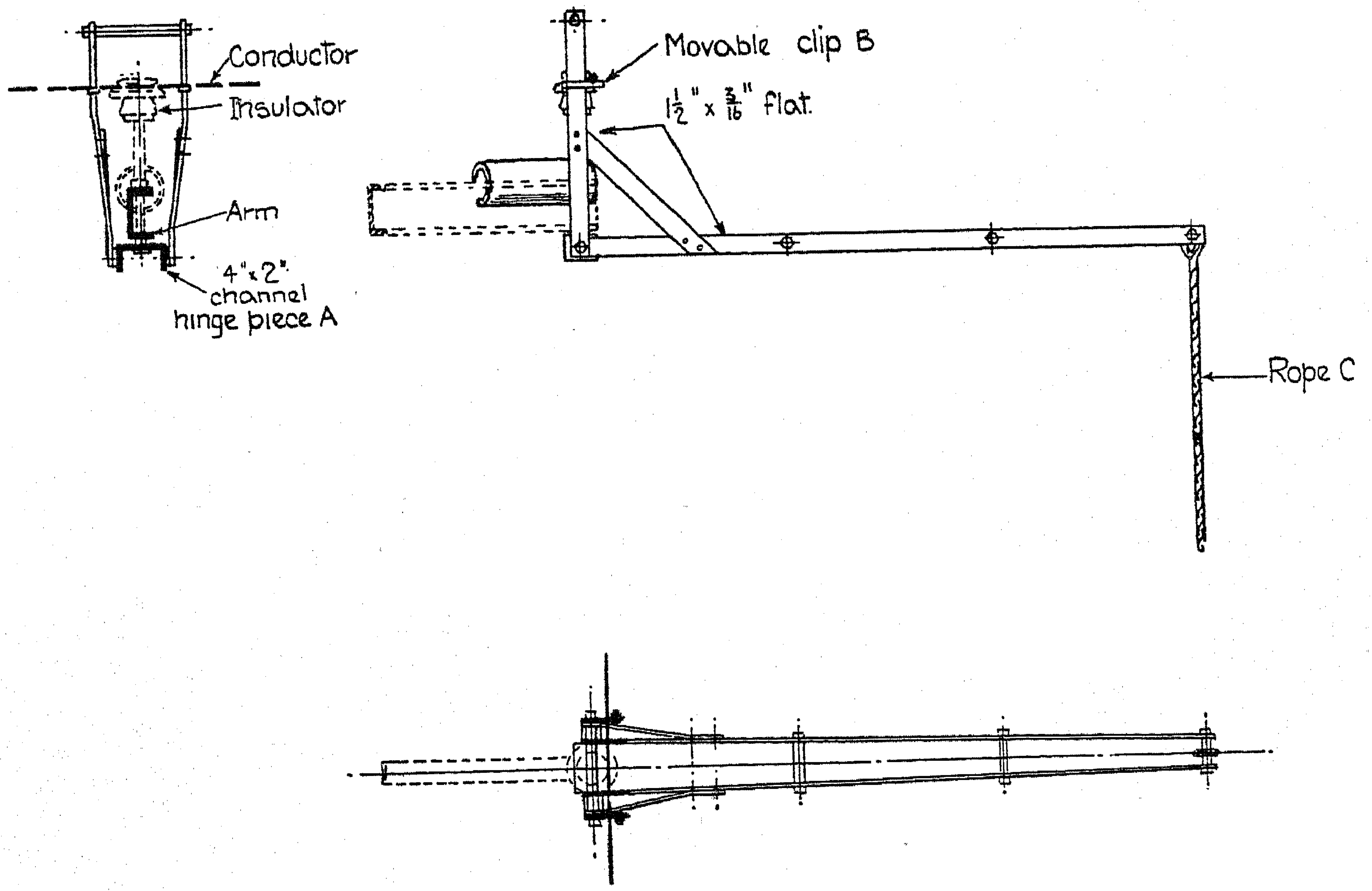


FIG. 10.—Device for taking strain on wire while chafer tape is being fixed at corner pole. Scale: 0·6 in. = 1 ft. (approx.).

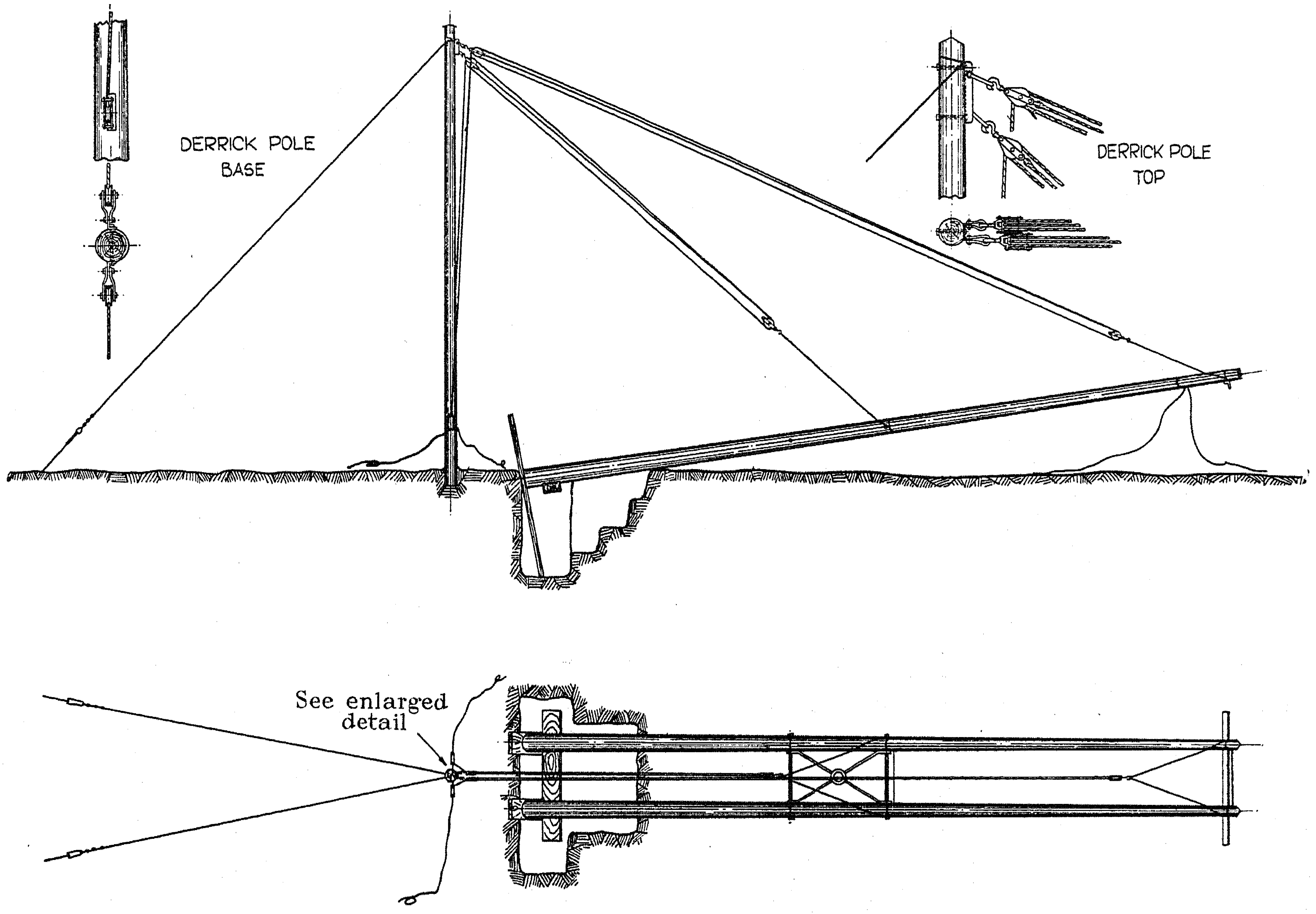


FIG. 11.—Equipment of derrick pole. Scale: $\frac{1}{12}$ in. = 1 ft. (approx.).

other about 2 ft. above ground line, as shown, the pull on the two block ropes is balanced, and further the position of the rope is rendered most suitable for efficient pulling by a number of men. This is not the case where the pull is on the rope directly down from the top block, as under such circumstances not more than two or three men can reach effectively. Owing to the balanced pull, the butt of the derrick pole requires to be only a few inches in the ground. Two flexible steel-wire ropes are permanently fixed to the derrick pole, and are temporarily secured to the thimbles of the permanent stay-rods by means of "U" clamps. Each set of rope blocks is attached to the "H" pole by means of a substantial steel-wire sling or chain. The method of operation should be clear from Fig. 11.

(5) HOUSE-SERVICE FUSE BRACKET FOR OVERHEAD SERVICES.

Providing details receive careful attention, there is no reason why overhead distribution should not be thoroughly reliable. The most vulnerable point of the whole scheme is the low-voltage leading-in cable, between the point where the overhead lines terminate and the supply authority's meter, which is invariably inside the consumer's premises. Unless the supply is fused on the feed side, a fault in the lead-in cable appears as a general

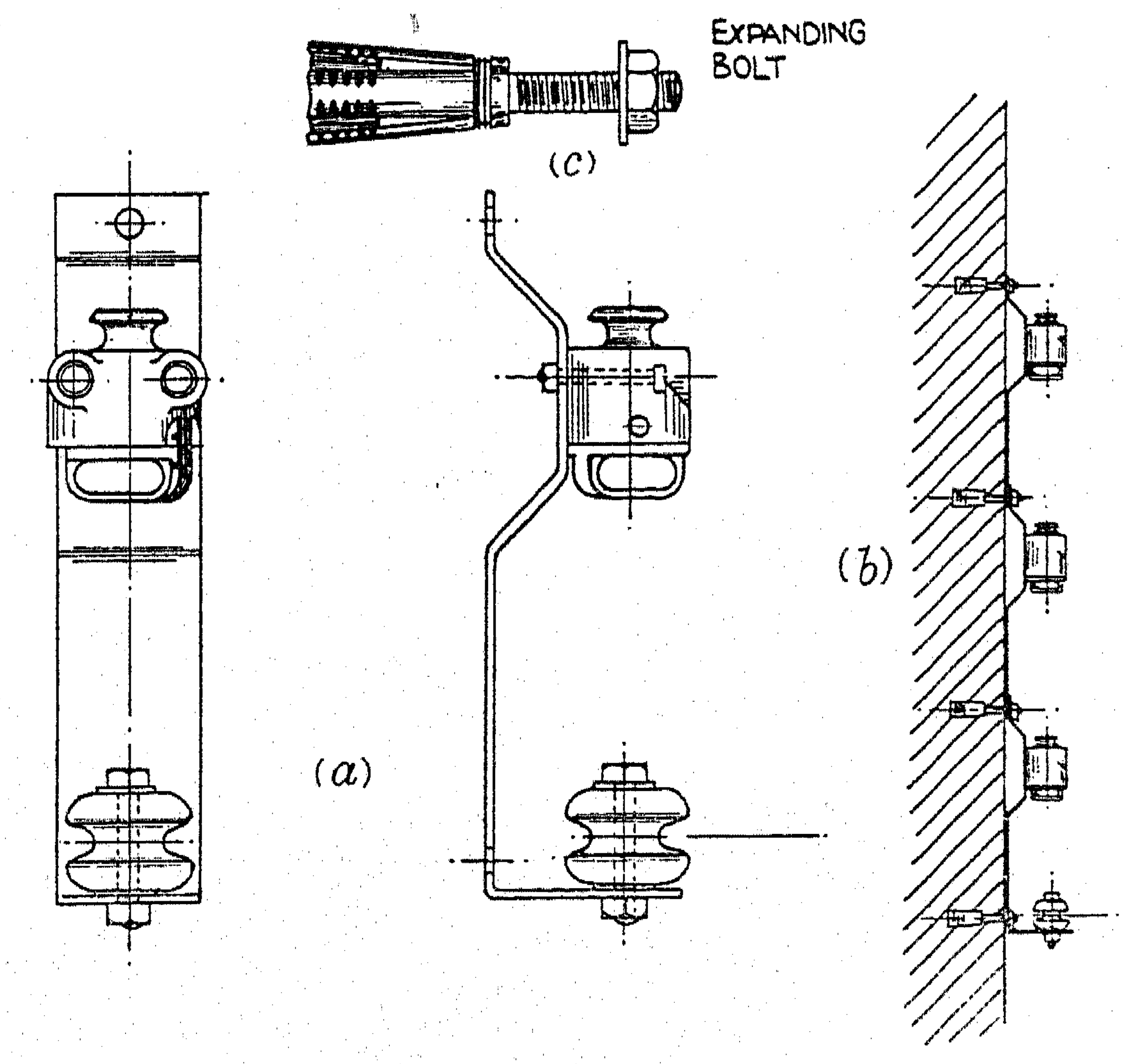


FIG. 12.

(*a*) Normal type of house-service bracket (scale: $1\frac{5}{16}$ in. = 1 ft.).
(*b*) Special type of house-service bracket for multi-phase services (scale: $\frac{7}{16}$ in. = 1 ft.).
(*c*) Expanding bolt (scale: $1\frac{5}{16}$ in. = 1 ft.).

mains fault, and invariably proves far more difficult and troublesome to locate than an ordinary line fault. For this reason the author recommends that all service lines should be fused, either at the nearest pole or immediately the overhead lines reach the consumer's premises, and preceding the lead-in cable. If the fuse is placed on the consumer's premises at the point of termination of the overhead service lines, the necessity for providing an insulated connector between the live service line and the lead-in cable is avoided.

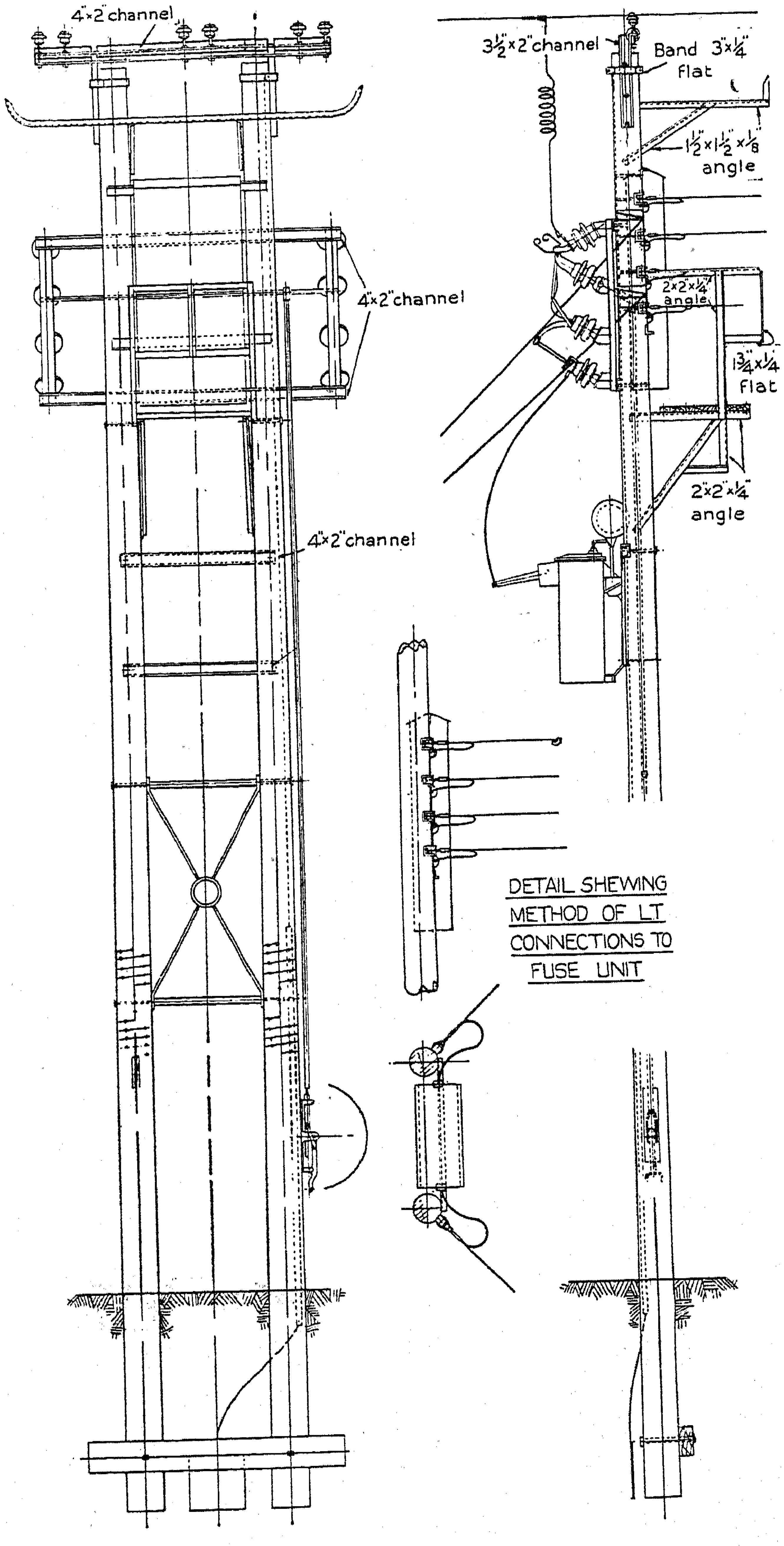


FIG. 13.—Details of construction of pole-type fuse control box. (The brace block at the base is actually let into the poles a depth of approximately 2 in.)

A number of fuses suitable for this purpose are now on the market. Fig. 12(*a*) shows a type of combined fuse and terminal bracket which is inexpensive and has proved most useful in service. For 3- and 4-wire services, the modified form shown in Fig. 12(*b*) has been adopted. To avoid the delays which would occur if fixing bolts had to be cemented into walls, an expanding type of bolt [Fig. 12(*c*)] is used for securing the brackets, both brackets and bolts being galvanized.

(6) LAY-OUT OF TRANSFORMER POLE TO INCLUDE ADEQUATE CONTROL OF FOUR OUTGOING LOW-VOLTAGE CIRCUITS.

Where a number of low-voltage circuits radiate from a transformer pole, provision should be made for fusing the individual circuits, as is usual with underground distributors radiating from a kiosk or substation. It was found that this called for a suitably designed pole-type fuse control box, if the usual jumble of low-tension V.I.R. tails, together with the costly labour on site which these involve, was to be avoided.

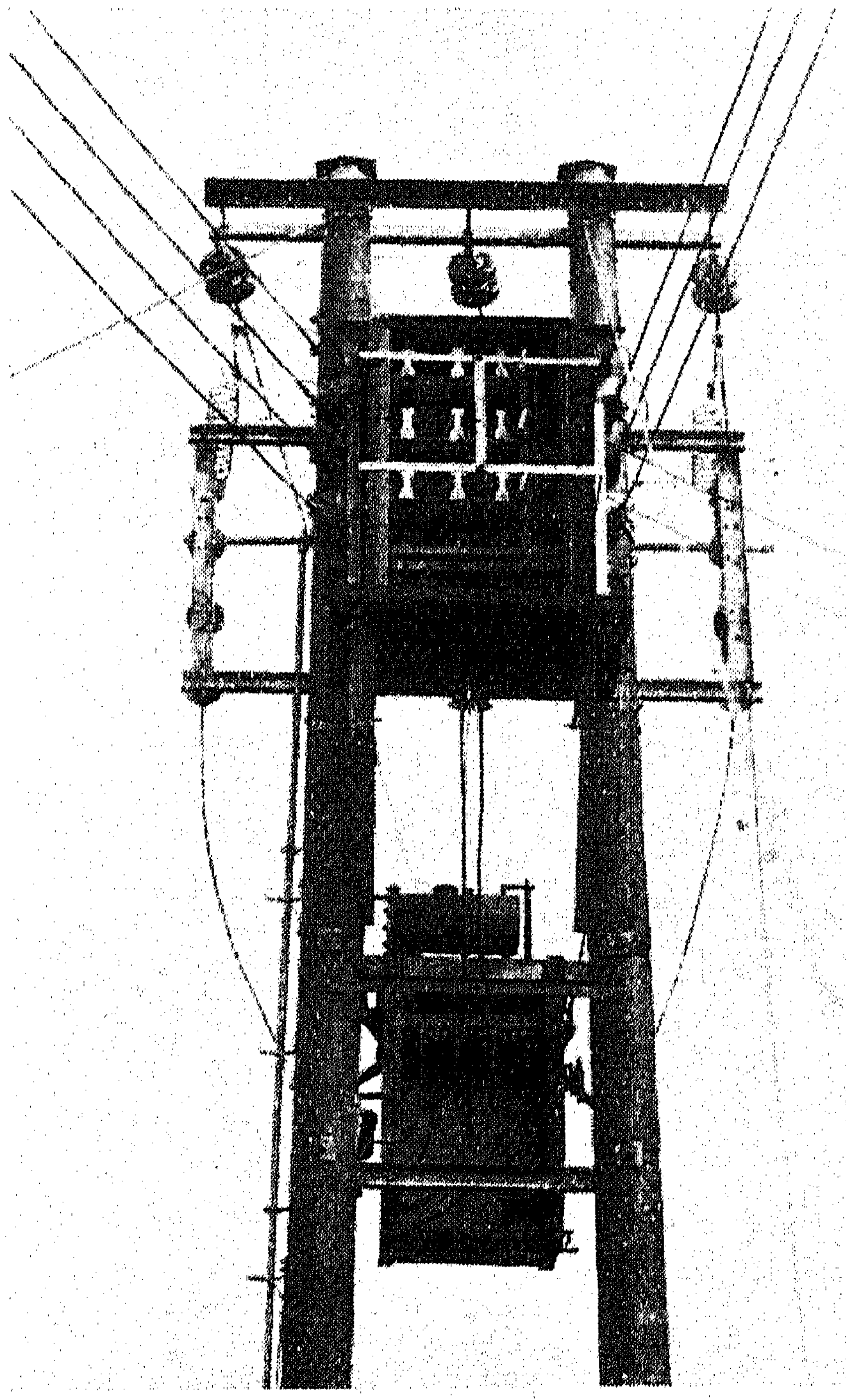


FIG. 14.—The complete fuse-box installation, with door of case open.

The arrangement illustrated in Figs. 13 and 14, designed and put into operation on the system with which the author is connected, has proved most serviceable in practice. In order to standardize the construction, provision was made at the outset for the containing case to be large enough to accommodate five 3-phase 4-wire feeder pillar fuse units in addition to three low-voltage lightning arrestors, together with their protecting fuses. Space is also provided in the base to house demand indicators, meters, or time switches, as may be required. The central fuse unit is arranged to control the incoming transformer circuit, and may be of either 150- or 300-ampere rating. This unit is particularly useful where more than one transformer is paralleled on to a single low-voltage network, as it may be used for isolating the transformer only, for inspection or repair, whilst allowing the low-tension circuits to be kept alive from a remote section. The two outer fuse units are of the normal type, without sealing chambers. Bushing insulators, consisting of standard reel insulators as used for supporting the low-voltage lines, are fixed in the sides of the containing case approximately 12 in. apart and horizontally in line with the cable terminals at the back of the fuse units. The complete fuse box is mounted on the pole at such a height that the respective bushings are in the same horizontal plane and adjacent to the " D " iron brackets on which the line conductors terminate. Thus, by leaving a few feet of extra length on the stranded line conductors at the time of making off, the actual conductors may be taken through the bushing insulators direct to the rear terminals of the two outer fuse units. This avoids the necessity and expense of clamp-type connectors on the line conductors, and the usual unsightly V.I.R. tails, which should be avoided wherever possible on pole-type transformer equipments. Two further spaces are available for additional fuse units. Should difficulty be experienced in accommodating and getting away four separate 4-wire low-voltage overhead circuits, it is a simple matter to fit compound sealing-type fuse units in these two spaces, and take a short length of underground cable down each leg of the " H " pole, to the start of other low-voltage routes some short distance away. This arrangement thus facilitates getting circuits away from a transformer pole, which, where more than two circuits are involved, is often a real difficulty. The illustrations indicate the method of fixing the complete fuse box, which, it will be noticed, is easily accessible from the platform.

Erection is simple, as by means of a set of rope blocks the complete unit can be raised and fixed in position in slots already cut in the pole to receive the main horizontal angle-iron supports on which both the fuse units and the outer shell are carried.

The base of the casing is filled in with expanded metal, as otherwise the interior would offer too tempting a home for nesting birds.

CONCLUSION.

The extensive use of overhead lines for the transmission and distribution of electrical energy in this country is comparatively new, with the result that very few design data or records of practical experience have been tabulated and published in what may be described as " tabloid " form. Owing to the frequent wide variations, particularly in the price of the metals for conductors, it is essential if comparisons are to be readily made of the relative economy of different types of construction, and variations in span lengths or conductor materials, that some such form of presenting the results of the application of basic principles should be more widely adopted. Only by such methods shall we reap the greatest benefits from our experience, and retain our position and prestige in the engineering world to-day.

The author was desirous of including graphs showing voltage-drops at different spacings and loadings for various classes of high-voltage conductors such as galvanized steel, steel-cored copper, copper-cored steel, copperweld, etc., but was prevented from so doing on account of the limited time at his disposal, and the fact that rural distribution is a phase of the industry with which he is not now in such close contact. It is suggested, however, that it could well form the subject of a further paper, which should fill a long-felt want.

ACKNOWLEDGMENTS.

The author wishes gratefully to acknowledge his indebtedness to British Insulated Cables, Ltd., Messrs. Richard, Johnson, and Nephew, and British Ropes, Ltd., for certain of the information given in Tables 7A to 7J, relating to the sags and stresses for various conductors. His thanks are also due to Mr. W. J. Marston, city electrical engineer and manager, Coventry, for facilities for the production of the drawings and graphs included in the paper.

[The discussion on this paper will be found on page 812.]

A REVIEW OF RECENT DEVELOPMENTS IN RURAL ELECTRIFICATION.

By D. Ross, Associate Member.

(*Paper first received* 5*th April*, 1934, *and in final form* 18*th February*, 1935; *read before the* Transmission Section 15*th May*, 1935.)

Summary.

The purpose of this paper is to review the progress made in simplifying the design and reducing the cost of rural distribution equipment. Comparisons are made of 11 000-volt distribution lines using various types of conductors.

The advantages of single-phase distribution are enumerated.

The design of transformers and their capital and running costs are considered, and suggestions are made for standardization of sizes.

Methods of obtaining cheap and reliable protection on the h.t. system by means of simple switchgear and fusegear are illustrated.

Particulars and costs of various types of l.t. distribution mains and services are given.

The difficulties encountered in some rural districts in obtaining adequate earths are recorded, and a strong recommendation is made that "all insulated" installations be adopted wherever practicable, and that in all other cases earth-leakage switches be employed.

Introduction.

During the last few years special attention has been given by many undertakings to establishing the supply of electricity in rural areas on a sound engineering and commercial basis. This has resulted in new designs and modifications to the recognized practice for distribution in towns and urban areas, which was found too expensive for rural distribution.

The author has been connected with several undertakings engaged in the development of rural areas, and he proposes to review the progress made and, from his own experience, to discuss some of the many new problems encountered and the general practice which has developed therefrom. For this purpose the paper is divided into the following Sections:—

(1) 11 000-Volt Distribution Mains.
(2) 11 000-Volt Switchgear and Fusegear.
(3) Protection of G.P.O. and Railway Circuits.
(4) Substations.
(5) Pole-Transformer Equipments.
(6) Transformers.
(7) Low-Tension Distribution Lines.
(8) Services.
(9) Consumers' Installations and Apparatus, Earthing, etc.
(10) System Protection, etc.

(1) 11 000-volt Distribution Mains.

High-tension overhead lines have now been erected in this country for over 30 years, commencing with a type of construction which closely followed Post Office practice. Many improvements have been made since then, and although at first sight no radical change has taken place during the last few years, a close investigation discloses that there have been many advances as a result of past experience and efforts made to reduce construction and maintenance costs.

For rural distribution, 11 000-volt 3-phase and single-phase lines have been wisely chosen, as the erection costs are not appreciably greater than those of 3·3-kV or 6·6-kV lines, whereas the carrying capacity is considerably greater.

Many attempts have been made to introduce various types of supports such as ferro-concrete, tubular steel, fabricated steel, etc., but the earliest form of support, a creosoted wood pole, still holds its own, as it is found much more economical to transport this type and to provide foundations for it, and, in addition, maintenance work such as painting is eliminated and facilities are readily provided for erecting transformers, switchgear, etc., and also for climbing without the use of ladders. It has also been found from experience that a life of at least 30 years can be expected for the average class of timber used, and considerably longer than this for the great majority of poles.

For rural distribution lines it is strongly recommended that single wood poles only should be used throughout, i.e. for intermediate, angle, section, and terminal positions, as not only will a single pole be found capable of carrying the largest sizes of conductors required on rural work but neatness and simplicity of design is obtained, kicking blocks being required only for the larger sizes of conductors, long-span work, or bad foundations. Perhaps the only exception to be made should be where duplicate circuit 6-wire lines are used or where 3-way or 4-way sectionalizing equipments are required, in which case "A" or "H" or other compound-type construction will be required.

By developing areas as far as possible on the "ring-main" principle, double-circuit lines can, and in the author's opinion should, be avoided, except possibly for short sections in the immediate vicinity of main substations.

Various types of conductors have been experimented with, and although it has been very difficult to justify using any other type of conductor than copper on account of its well-known reliability and high conductivity, steel-cored aluminium and galvanized-steel conductors have much to recommend them on account of their higher tensile strength, resulting in longer span construction and cheaper and less conspicuous lines, less wayleave difficulties, reduced damage to crops, fewer insulators, and consequently greater immunity from failures and lightning disturbances.

Before mentioning any costs for 11 000-volt lines, it should be pointed out that much confusion occurs owing to unqualified statements of costs per mile. One reads many exaggerated claims of low costs per mile, but engineers of experience will appreciate the difference between the costs, say, paid to a contractor, which usually are for erection only, and "all-in" costs. The latter must include such incidental costs as obtaining wayleaves, Post Office and railway crossing costs, damages, etc.

By the use of steel-cored aluminium (S.C.A.) conductor, with equivalent copper sections as low as 0·05 sq. in., spans from 400 to 500 ft. can be obtained, the construction cost of which is approximately £302 per mile. The cost of negotiating wayleaves, wayleave rentals commuted to 18 years' purchase, tree-cutting, crop damage, and protection to Post Office and railway circuits, works out at approximately £62 per mile, making a total cost of £364 per mile.

The construction cost of a 3-phase line using 0·05-sq. in. equivalent cadmium-copper conductors designed for spans of 420 ft. is approximately £320.

The construction cost of a 3-phase line using 0·05-sq. in. (3/·147) copper on spans of 350 ft. is approximately £318, the price of copper being calculated on electrolytic wire bars at £37 5s. per ton.

It will therefore be seen that there is no appreciable difference in cost with various types of conductors, and the decision must rest with the engineer, depending upon the configuration of the country and the class of land over which the lines will pass, and, what is more important, on reliability, neatness of construction, and reduction in incidental costs such as wayleaves and compensation for damage. In the opinion of the author the S.C.A. conductor line is the cheapest for main distribution when all costs are taken into account. For small loads and short distances, however, galvanized-steel conductor has been found to be cheaper.

The number of tension insulators should be kept to a minimum by maintaining the distance between section poles as near as possible to a maximum of 2 000 yards, reducing the number of heavy angles, using pin-type insulators on light angles, and avoiding the location of section poles or heavy angle poles at road crossings. It has hitherto been difficult to avoid the use of tension insulators at uplift positions, but a recent design of pin insulator capable of withstanding uplift not exceeding 80 lb. makes possible a reduction in the insulator cost for such a pole on a 3-wire line from £7 4s. with two disc tension insulators to £2 10s. with the uplift-type pin insulators. Not only is a considerable initial saving effected but the appearance of the line is improved.

The top-hamper steelwork should be galvanized and so designed as to be easily erected with the minimum number of fixing bolts and freedom from bird traps. In the past too little consideration has been given to this feature, but it has been found from experience that bird trouble can be overcome by giving adequate clearance between phases and to earth. It is suggested that at least 18 in. clearance to earth should be given. Fig. 1 shows a typical example of this type of construction.

Little can be added to the information already available regarding 11-kV insulators, except that the values given in B.S.S. No. 137 are considered to be on the low side for overhead-line construction. Insulators for 11-kV lines should have the following minimum characteristics:—

Dry-flashover value	75 kV
Wet-flashover value	53 kV
Puncture value	140 kV

It is the author's opinion that S.C.A. conductors should be as satisfactory as copper conductors, provided a galvanized soft-iron wire is used as a binder. Soft aluminium binders are most unreliable, as the material is frequently stretched during erection, resulting in a failure at the first or subsequent storms.

The question whether an aerial earth-wire should be erected is a controversial one. By its elimination a saving can be effected owing to the reduction in size of pole and in cost of conductor and supporting fittings, but against this must be considered the installation of separate earth plates at each support, the resistance of which may be of a high value, cases having been found where the resistance of individual earth plates has exceeded 300 ohms. This high resistance may affect the correct operation of automatic switchgear and give rise to possible danger to human beings, livestock, and property, should a fault occur at that point.

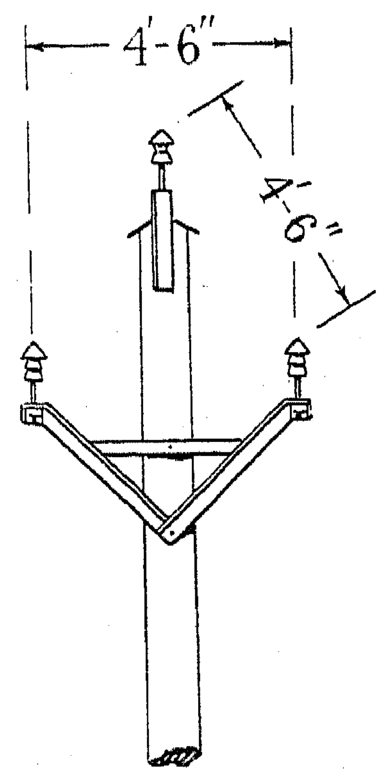


FIG. 1.

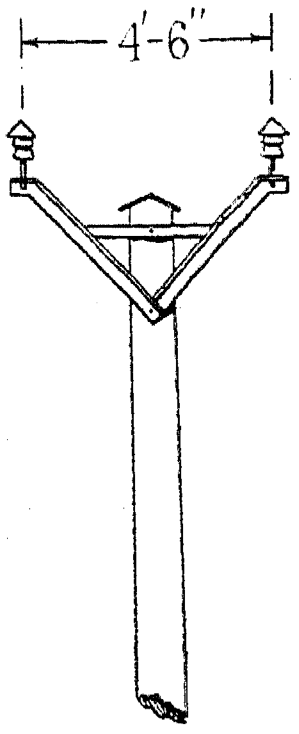


FIG. 2.

On the other hand an adequate earth is always available for the earthing of transformer neutrals, etc., which is of considerable importance in hilly and sandy districts. The cost per mile of erecting an aerial earth-wire is approximately £25 for 7/14 S.W.G. galvanized steel, so that even when faced with the possibility of spending an additional £10 to find a suitably low earth resistance at a transformer there would appear to be some justification for eliminating the continuous aerial earth-wire. An aerial earth-wire can always be erected for a few spans should high-resistance earths be encountered.

Spur Lines.

For spur lines to supply farms, large residences, small villages, etc., which cannot be dealt with direct from the main line, it is recommended that the most suitable type of construction is galvanized-steel conductor, compounded overall, and erected on creosoted single wood-pole supports with spans of approximately 500 ft. This type of construction is mechanically sound; little trouble will be experienced from clashing of conductors or breaking of binders; and the life of conductor, galvanized by modern methods, can be expected to exceed 20 years. The author has experience of a galvanized-steel earth wire which had been in service 18 years and which, after careful examination, was found to be in excellent condition. The line was within a few miles of the sea and the galvanizing was done during the War years when present improved methods were unknown. In some districts the life may be considerably increased, whereas in industrial districts it will be much shorter, but obviously in such districts this type of conductor should not be used. As we are mainly concerned with rural districts there is every reason to think that this material will give complete satisfaction. Two sizes of conductors are suggested. Particulars and cost of erection are given in Table 1.

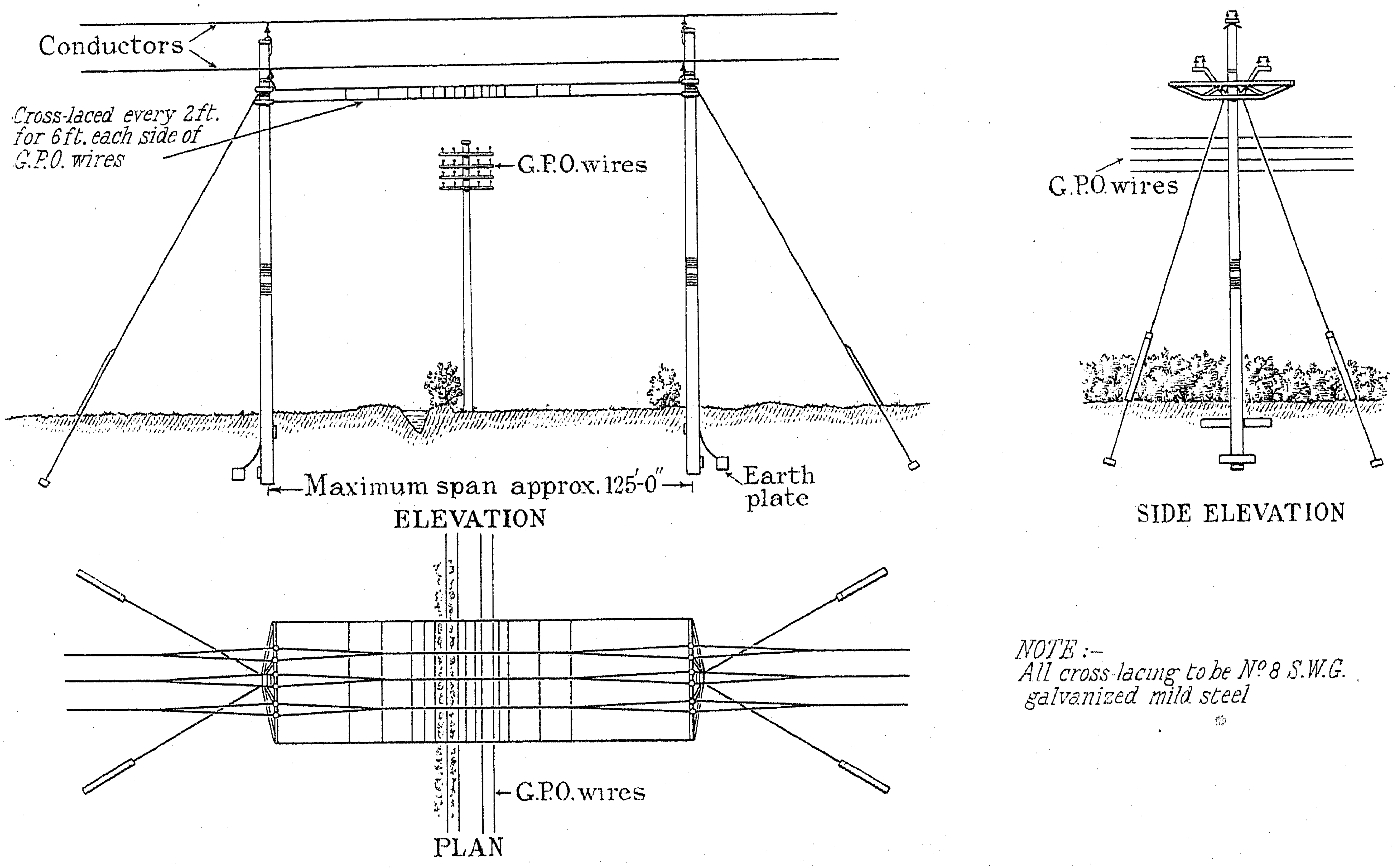

Conductors
Cross-laced every 2ft. for 6ft. each side of G.P.O. wires
G.P.O. wires
Maximum span approx. 125'-0"
Earth plate
ELEVATION
G.P.O. wires
SIDE ELEVATION
G.P.O. wires
PLAN
NOTE:-
All cross-lacing to be Nº 8 S.W.G. galvanized mild steel

Fig. 3.

Table 1.

Single-phase		Three-phase
7/14 S.W.G. 60 tons per sq. in. breaking stress £150 per mile	7/12 S.W.G. 45 tons per sq. in. breaking stress £180 per mile	7/12 S.W.G. 45 tons per sq. in. breaking stress £225 per mile

The above figures exclude wayleave costs, damage to crops, tree-cutting, and protection of Post Office and railway circuits, etc.

A typical design is shown in Fig. 2. Steelwork and insulators can be identical with those used on the S.C.A. lines, but lighter and shorter poles will suffice, and kicking blocks on intermediate poles are unnecessary.

Another advantage of the single-phase system is the particularly neat type of construction which can be obtained and also the simplified type of Post Office cradle-guard which can be erected (see Fig. 3).

Underground Mains.

Before disposing of the subject of 11 000-volt mains, reference should be made to the possibilities of using underground cable manufactured in accordance with B.S.S. No. 480, as there may be special circumstances where this method can be economically employed, i.e. where the ground is of a soft nature, resulting in low excavating costs; where a shorter underground route can be obtained; or where special constructional difficulties and/or costs are involved with overhead lines, such as Post Office circuits, and canal or railway crossings.

The costs of laying 1 mile of 11 000-volt cable are given in Table 2.

Table 2.

Size	Armoured	Unarmoured
0·0225 sq. in. ..	£595	£482
0·04 sq. in. ..	£683	£554

In addition to the above a specially designed rural cable for 11 000 volts is being produced by one manufacturer for laying in conjunction with a mechanical excavator arranged for cross-country routes. It would appear, however, that the excavator can be economically used only in favourable circumstances.

(2) 11 000-volt Switchgear and Fusegear.

With a view to reducing the number and duration of interruptions to a minimum, it is recommended that section isolators should be inserted in the lines at accessible positions, say 4 to 5 miles apart. These enable the line to be sectionalized rapidly in the event of a fault, and also for repairs and connecting up new spur lines and new transformer equipments. This switch should preferably be of the horizontal, triple-pole type, and capable of being mounted on the top of a single pole and operated from the ground-level. Various types are now available and can be obtained for as low as £11 10s. and erected complete for £15 11s. Fig. 4 shows a typical example of the switchgear. At interconnecting points it is necessary to use a different type of equipment, and a typical 3-way sectionalizing equipment is shown in Fig. 5. Horizontal or vertical switchgear can be used for this purpose, but it is desirable that the branch line should be protected with some suitable type of fusegear.

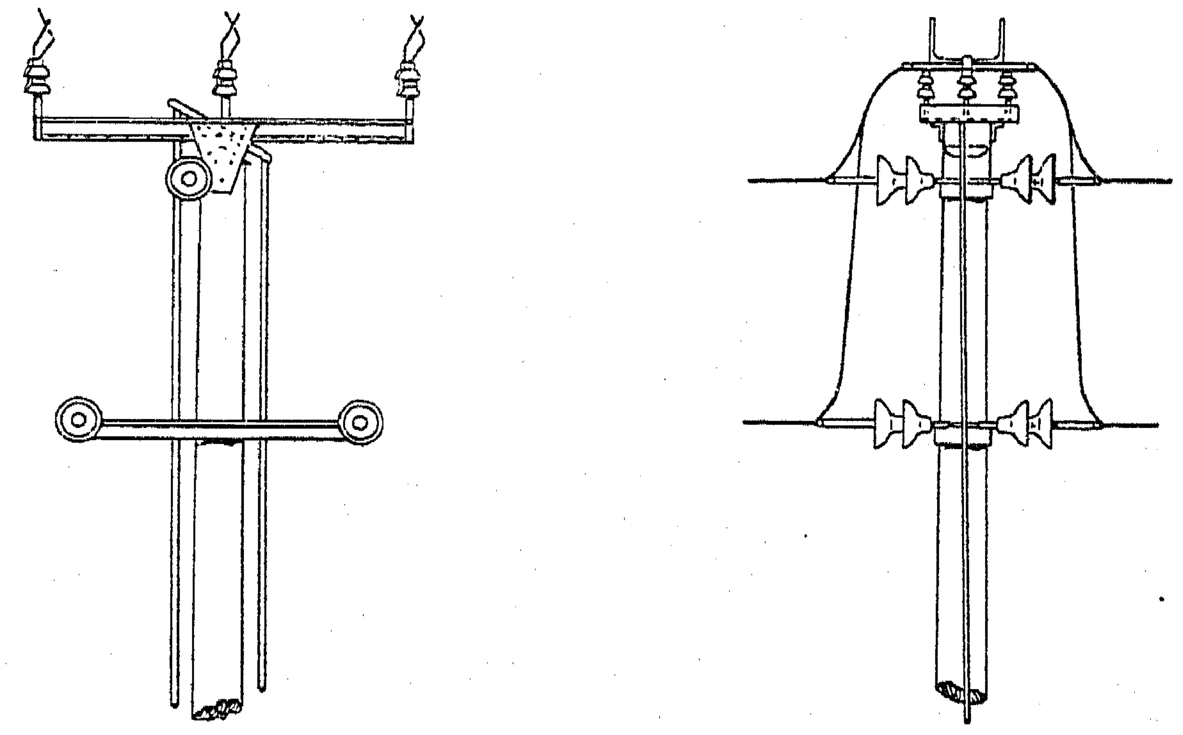


Fig. 4.

For the protection of subsidiary and important branch lines and to avoid men having to climb to insert fuses it is strongly recommended that a suitable type of pull-down fusegear should be adopted, i.e. a movable portion of the fusegear is brought to the ground-level to enable the fuses to be inserted. There are various types of this gear on the market which operate satisfactorily, are cheap in first cost (viz. £22), and are easy to install.

As an alternative to pull-down fusegear there are now several makes of pole-mounting automatic oil circuit-breakers which are reasonable in cost (viz. £34) and give every satisfaction. Some of them are equipped with re-closing devices. The disadvantage of oil switches is that inspection, maintenance, etc., is difficult unless air-break isolators are provided on either side, which obviously adds considerably to the cost. At more important control points, however, there is ample scope for the use of this type of switch.

For the protection of spur lines and transformers it is not considered necessary to install pull-down gear; instead an inexpensive plug-in type of fuse is used, which is easy to install, and to operate from the ground by means of an insulated rod 20 ft. in length. The fuse carrier can readily be inserted or removed in less than 1 minute, in one operation. The cost of a single-phase equipment erected complete is £7 17s., and of a 3-phase equipment erected complete, £11 5s. This unit is suitable for the

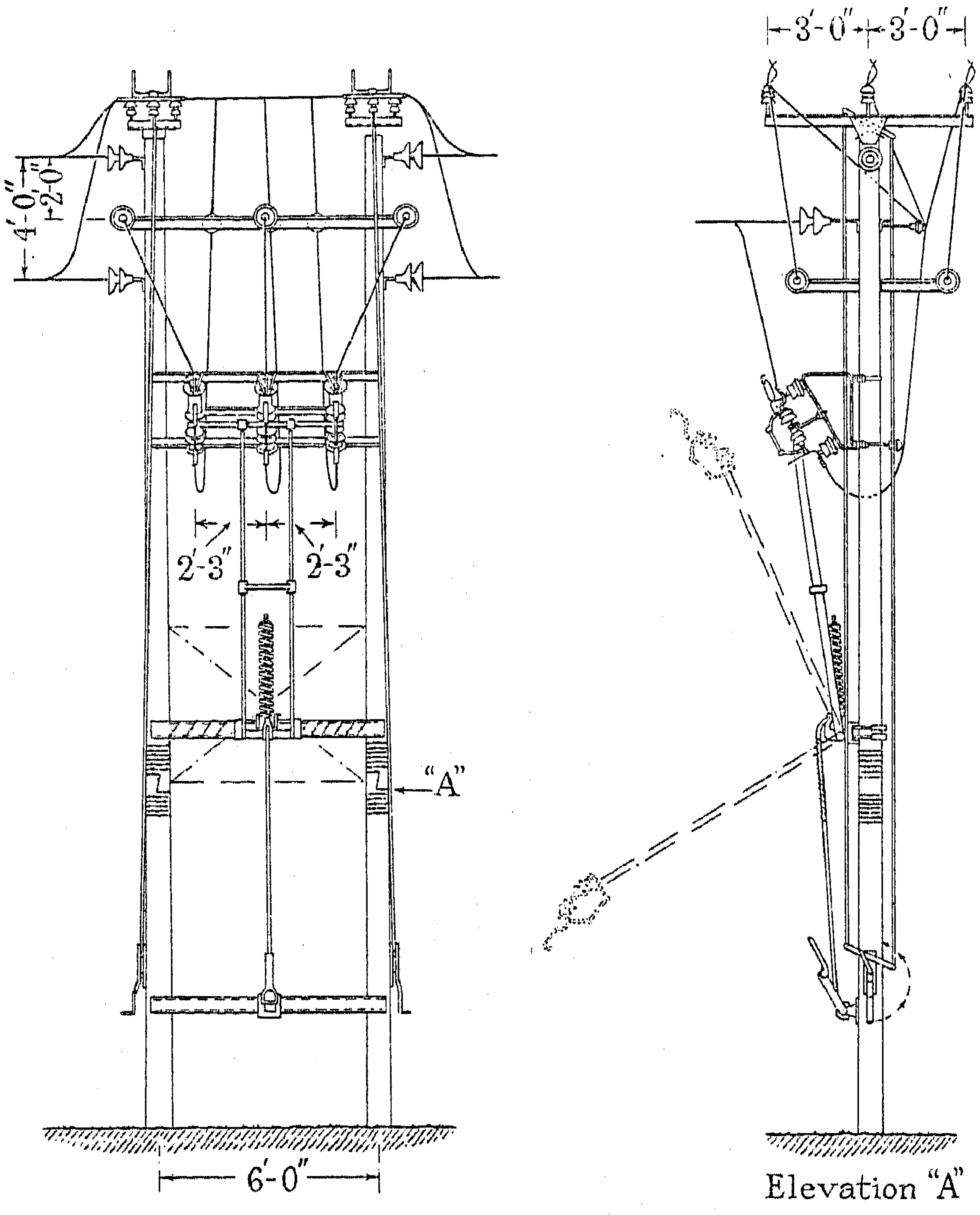


Fig. 5.—Sectionalizing switchgear.

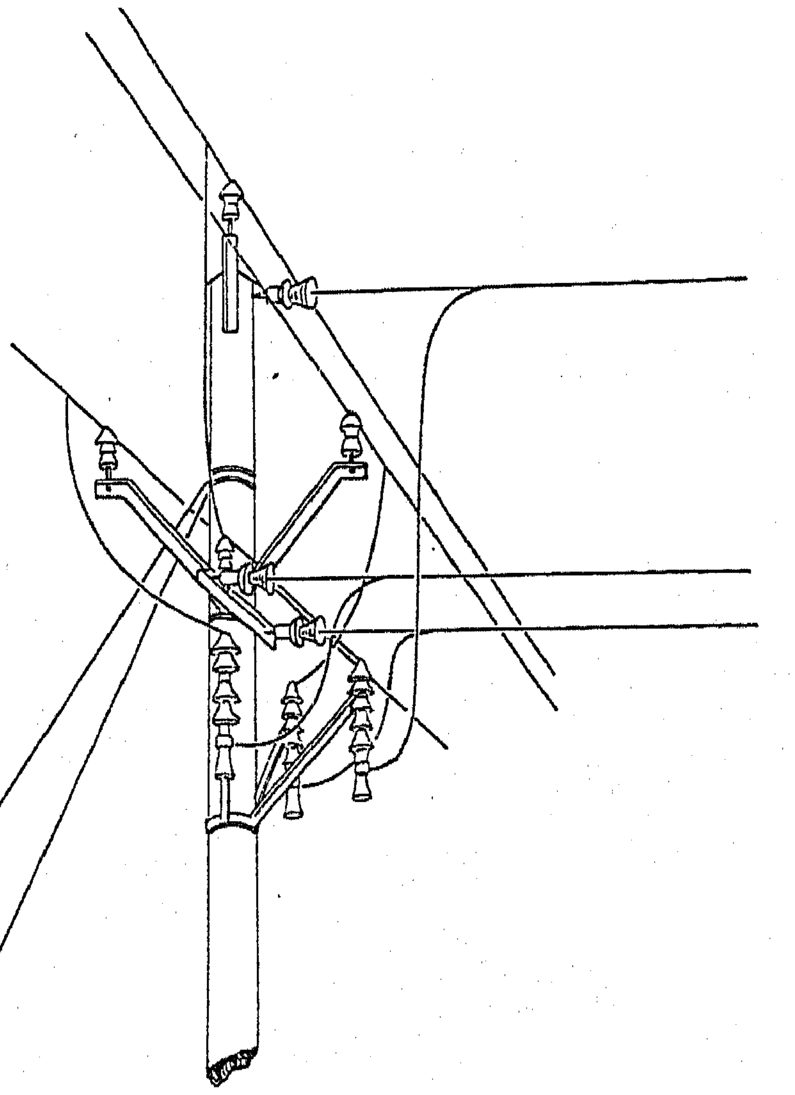


Fig. 6.—Fused tee-off arrangement.

cartridge type of fuse having a rupturing capacity of 100 000 kVA. There are several makes available of this type of fuse, some of which use the well-known liquid filling.

Another advantage of this type of gear is the ease with which it can be erected in the first instance and the simple manner in which connections can be made between the line and the apparatus to be protected, without introducing bird traps and restricting clearance between phase and earth. Fig. 6 shows a spur line protected by means of this type of fusegear.

The protection of pole transformers is also a simple matter with this type of fusegear, as illustrated in Fig. 7.

Rewirable types of fuses have been tried but have not proved satisfactory. This would appear to be due to the relatively small wire suspended in air and encased within an insulating tube having a high specific inductive capacity and with a gap between the wire and the tube, which is subjected to an electrical stress, which in turn gives rise to a corona discharge. The ozone generated by this discharge, or possibly a nitric-acid compound, attacks the fuse wire and results in premature failure.

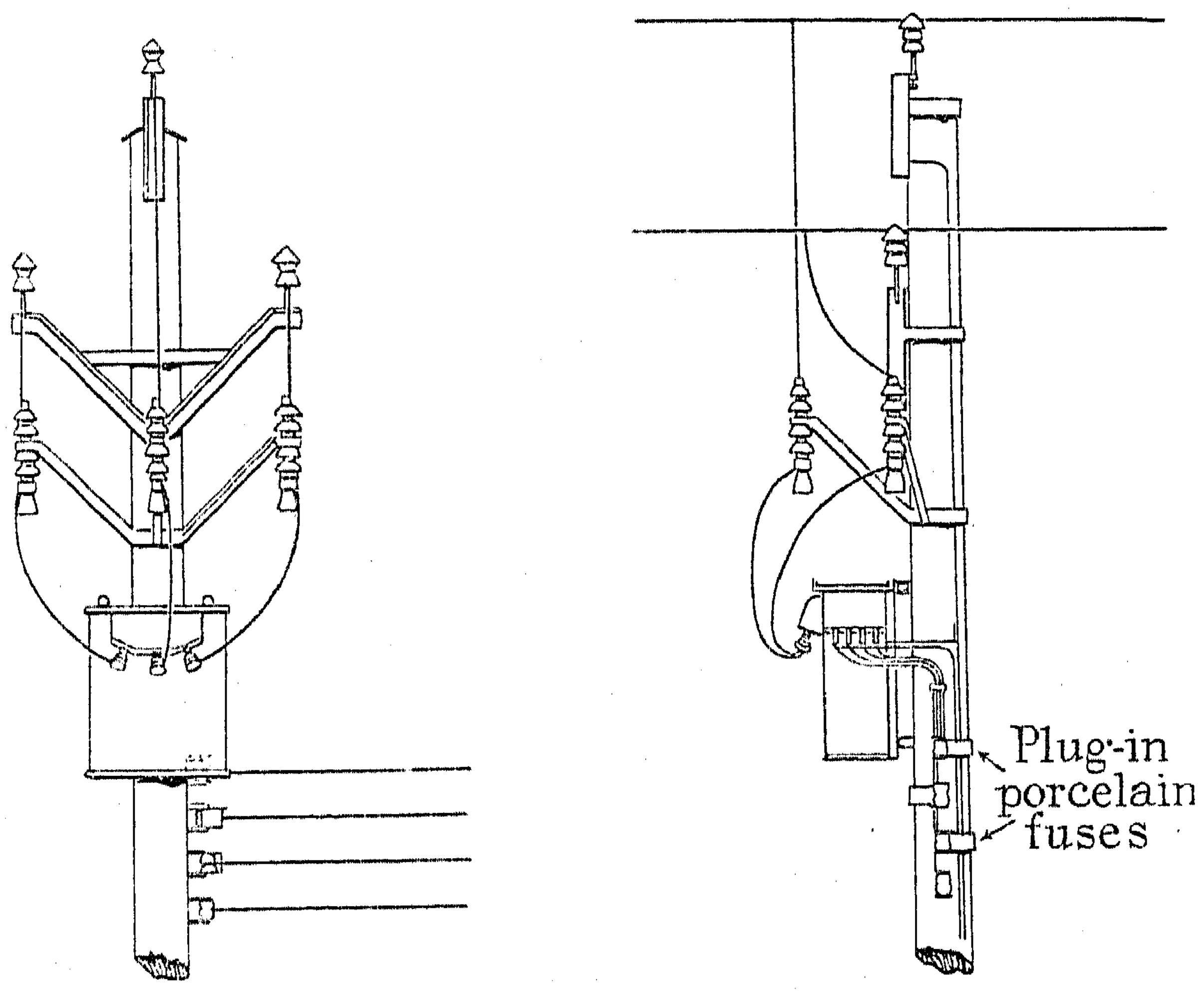


FIG. 7.—Pole-transformer equipment.

(3) PROTECTION OF G.P.O. AND RAILWAY CIRCUITS.

The protection of Post Office and railway circuits adds considerably to the construction costs of extra-high-tension lines. For instance, the standard cradle-guard requested by the Post Office (Technical Memorandum E-in-C 231) will cost approximately £60, and not only is this cradle guard unsightly but it frequently involves considerable wayleave difficulties. An alternative type of cradle guard has been designed which meets with the approval of the Post Office; this is shown in Fig. 3. The cost of the guard for a 2-wire line is approximately £40, and for a 3-wire line approximately £48.

In certain instances the Postmaster-General is prepared to place his circuits underground. The cost of doing this varies according to the number of circuits and to the length required to be placed underground, but the average price for a crossing in a rural area works out at £32. Generally speaking it is found more economical for the Post Office to place their circuits underground, but in many cases they are not prepared to do so.

TABLE 3.

Cradle-guard crossings		P.O. circuits diverted underground
Three-phase line	Single-phase line	
£31·2 per mile	£26 per mile	£20·8 per mile

An analysis of a large rural scheme gives the average of 0·65 Post Office crossing per mile, resulting in the costs shown in Table 3, which are an appreciable proportion of the total cost.

If a Post Office crossing occurs in a short spur line the cost of protection may be as high as one-third of the cost of the whole line. It is clear, therefore, that the relaxation of the conditions imposed would in all cases materially assist rural distribution and in extreme cases might render possible the erection of an individual spur line at present prohibited owing to the cost of the Post Office crossing.

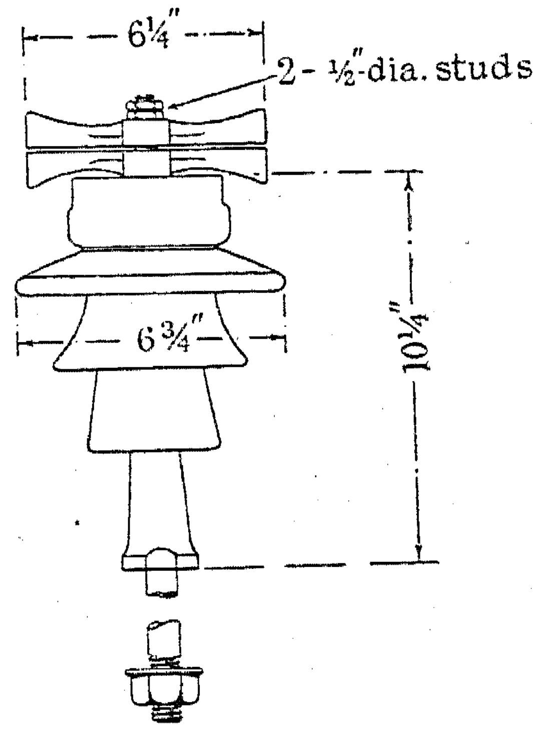


FIG. 8.—Uplift insulator.

Regarding the protection of railway circuits, the railway companies almost invariably request that their circuits be protected by means of a 4-post inverted-type cradle-guard, the average cost of which is £40. The number of railway crossings per mile on rural distribution schemes averages 0·093, resulting in a cost of £4. Here again it is felt that a saving could be effected by the erection of a simpler type of guard.

The protection required for low-tension circuits is dealt with under "Low-Tension Overhead Lines."

(4) SUBSTATIONS.

For rural distribution work, only the main substations can be constructed of brick or stone and equipped with relatively expensive oil circuit-breakers. Such main substations may be required where the bulk supply is received and/or where control and interconnection of important feeders is necessary. Only in such cases can the installation of automatic oil-break switchgear be justified.

The question whether outdoor or indoor switchgear should be used is a debatable one, but it has been found generally that the additional expense incurred in making switchgear suitable for outdoor use is greater than the cost of a building, e.g. an 11 000-volt 8-panel compound-filled switchboard with busbar coupler for outdoor use would cost £1 477. An indoor compound-filled switchboard for the same service would cost £949, while the cost of the building would be £200, making a total cost of £1 149. Against this, of course, it must be considered that with outdoor gear it may be feasible to take bare connections on to the overhead lines, whereas with the switchgear installed indoors it would be necessary to use cables, which might bring the cost up to that of an outdoor substation. The advantages of being able to operate, inspect, and maintain switchgear under cover would decide in favour of an indoor substation.

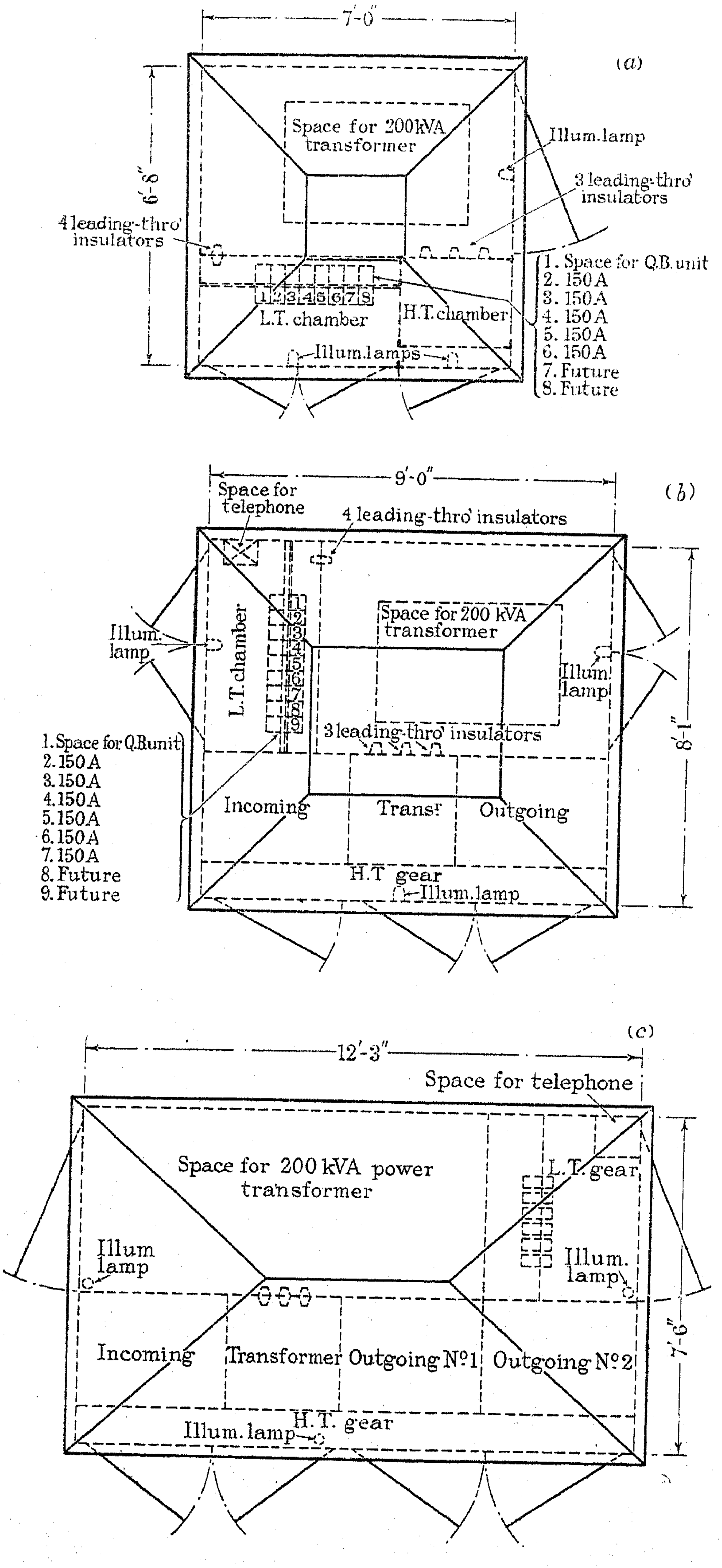


Fig. 9.—Kiosks.
(*a*) Type 1. (*b*) Type 2. (*c*) Type 3.

For the majority of distribution schemes the steel-kiosk substation will be found to be the most economical proposition, and a site for such a substation can readily be obtained. Three different types, each of which has its own use, are illustrated in Fig. 9. Generally speaking, the high-tension compartment should consist of oil-break or air-break switchgear for controlling the incoming and outgoing feeders in the case of ring mains, and air-break isolators and fuses for local transformer protection. Ample accommodation should be provided for the transformer, and provision made for at least a 250-kVA transformer, although in the initial stage a 100-kVA transformer may only be necessary. For the protection of the outgoing low-tension feeders distribution fuse units are used, and where interconnection on the low-tension network is possible the Home Office stipulates that an isolator or a switch must be provided between the transformer and the low-tension control panel. A suitable quick-break isolator to line up with the fusegear units is obtainable. It is recommended that maximum-demand indicators should be installed on each phase so that the loading can be checked.

The ventilation of the kiosk should be given due consideration, and at the same time steps should be taken to avoid the ingress of moisture or dust by providing suitable baffles. Adequate steps should be taken by means of simple interlocks to prevent access to the high-tension compartments, and an insulated dropdown platform provided in the l.t. compartment. The steel structure should consist of sheet steel not less than $\frac{3}{16}$ in. thick, and it is strongly recommended that the steel should be of the non-rusting type, or should be sand-blasted before painting, as the subsequent painting and maintenance of kiosks is difficult. Hinges and locking bars should be robust and equipped with grease nipples.

(5) Pole-Transformer Equipments.

The low cost of installing pole-mounting transformers has resulted in their extensive use. Sizes up to 25 kVA can be hung on a simple cross-arm on a single pole, and a 50-kVA transformer can be erected on a platform on a single pole. For 100 kVA and above it is desirable that an additional pole be erected alongside the existing pole to carry the platform. It is not considered necessary, except when erected on main lines, for each pole-type transformer to be protected separately, but fuses should be inserted to protect the spur line, and it is suggested that as many as *eight* transformers, depending on size, can be protected in this way with considerable economy.

Many failures have occurred with copper connecting tails between e.h.t. fuses, transformers, and the line conductors, owing to fracture taking place at the points of support. There is also a risk of clashing between tails, as clearances are usually restricted. To obviate both the above difficulties there has been developed, for use on the scheme with which the author is at present connected, an insulated tail comprising a 7/·068-in. galvanized-steel conductor having a compound rubber ozone- and weather-proof insulation with an electric stress of 6 000 volts. Tails of this type have proved quite satisfactory in use.

For the control of the low-tension lines a plug-in fuse is available which can be operated from the ground-level by the same operating rod as that used for extracting the high-tension fuses, thus eliminating the climbing of poles with extra-high-tension equipment. This has long been the aim of the Home Office.

(6) TRANSFORMERS.

Sizes and Types.

The sizes of transformers should be standardized, and the sizes given in Table 4 are recommended.

TABLE 4.

Single-phase	Three-phase
kVA	kVA
5	15
10	25
15 (3-wire)	50
25 (3-wire)	100
50 (3-wire)	150
	200

The author is of the opinion that the installation of transformers smaller than 5 kVA cannot be justified, for the following reasons.

(*a*) *Cost.*—The cost per kVA of small transformers rises rapidly for outputs below 10 kVA, on account of the comparatively high percentage of the cost represented by such parts as tank, terminals, and insulators, which are not reduced in proportion to the output, and also to the increased cost of the small wires used for the high-tension windings. The approximate variation of price with output will be appreciated from Table 5.

TABLE 5.

Output	Selling price (approx.)	
	Three-phase	Single-phase
kVA	per cent	per cent
25	100	100
15	84	81
10	74	70
5	64	56
1½	52	48

(*b*) *Efficiencies and Regulation.*—The regulation and efficiencies of the smaller transformers are comparatively bad unless these are designed more liberally than the larger units, in which case there would be little saving in the cost. The regulation of a 1·5-kVA transformer is much worse than that of a 5-kVA transformer with a load of 1·5 kVA. This would be about 6·0 per cent in the former and 1·2 per cent in the latter on unity power factor. The iron losses of the 1·5-kVA transformer would be less than that of the 5-kVA transformer, but would barely compensate for the loss of revenue due to the increased voltage-drop.

Table 6 shows a comparison of annual costs and losses, etc., of a 1·5-kVA transformer with a 5-kVA transformer having a load of 1·5 kVA. The basic figures are of course estimated to represent a fair approximation of conditions in rural districts.

TABLE 6.

	5 kVA	1½ kVA
	pence	pence
Annual cost of iron losses	267	163
Annual cost of copper losses at 15 per cent load factor on 1·5-kVA transformer	19	100
Interest and loan repayment charges, at 8 per cent	384	317
Annual revenue losses due to regulation at 15 per cent load factor. Units at 2d	48	240
Total	718	820

The above figures show that on the basis of the annual costs of operation, the installation of a 1·5-kVA transformer could not be justified economically as against a 5-kVA transformer, even where the maximum demand is not expected eventually to exceed 1·5 kVA.

For small distribution schemes, i.e. where several consumers are clustered together, the size of transformer should not be less than 15 kVA, having regard to the diversity of load on consumers' apparatus and between one consumer and another. On the average 1 kVA per consumer should be ample.

Single-phase transformers are cheaper in first cost than 3-phase transformers, on account of the smaller core, less copper, reduction in tank size, reduction in number of terminals, etc., and, what is of considerable importance, the no-load losses are less. This is a particularly strong reason why single-phase 2-wire and 3-wire distribution should be used for smaller distribution networks. A comparison of costs and losses of 3-phase and single-phase transformers is shown in Fig. 10. It will be appreciated that to get a transformer with low load-losses regulation must be sacrificed, but as the majority of the smaller transformers will be used adjacent to the consumers' premises the regulation, except for losses, is not so important as with transformers for distribution networks. In the case of the large transformers (25 kVA and upwards), however, these will mainly be required for the supply of large distribution networks where the radius of supply is considerably greater and therefore the regulation of the transformer is of paramount importance. No-load losses are of less consequence in cases where a number of consumers are supplied from a transformer. With a 5-kVA transformer supplying one consumer only, the loss per consumer is 438 kWh per annum, but with a 100-kVA transformer supplying 300 consumers the loss per consumer falls to 18·6 kWh per annum.

Economical Design of Small Transformers.

There are three important variables involved, the core loss, the copper loss, and the initial cost. In the case of transformers for rural distribution the load factor is usually very low, so that the importance of low copper loss is much reduced except as to its effect on regulation.

The actual amount of core loss should be considered in conjunction with its relation to the cost price of the transformer, as it is quite possible with an expensive design that very low core loss may be less economical than a cheaper design with higher losses, as much depends on the proportions and the relation of active material to tank dimensions and oil quantity, and on manufacturing costs. A direct comparison of different designs can be made on the basis of the sum of the cost price and the capitalized value of the core and copper losses.

Mechanical Features.

The transformer should be of robust design, capable of withstanding surges due to switching operations and lightning disturbances, and the insulators should have a higher flashover value than the remainder of the insulators on the line. The most important points to be considered are the tank, the tank fittings, and the terminal arrangement. It is not considered necessary to fit an oil-conservator system, or an oil-sealed breather valve or calcium-chloride breather, except in the large sizes of transformers (50 kVA and upwards). A completely weatherproof cover is essential with a flange joint, the flange to be bent over to form a hood. Oil gauges are only necessary on the large sizes of transformers, say 50 kVA and upwards, and the tank should be constructed of plate of not less than $\frac{1}{8}$ in. thickness.

Terminal Arrangement.

Terminals are fitted either on the cover or on the side of the tank, but the latter position is obviously preferable for the inspection of the transformer or changing of tappings *in situ*. Two types of terminals are available, the upright petticoat type and the inverted type inserted in the side of the tank.

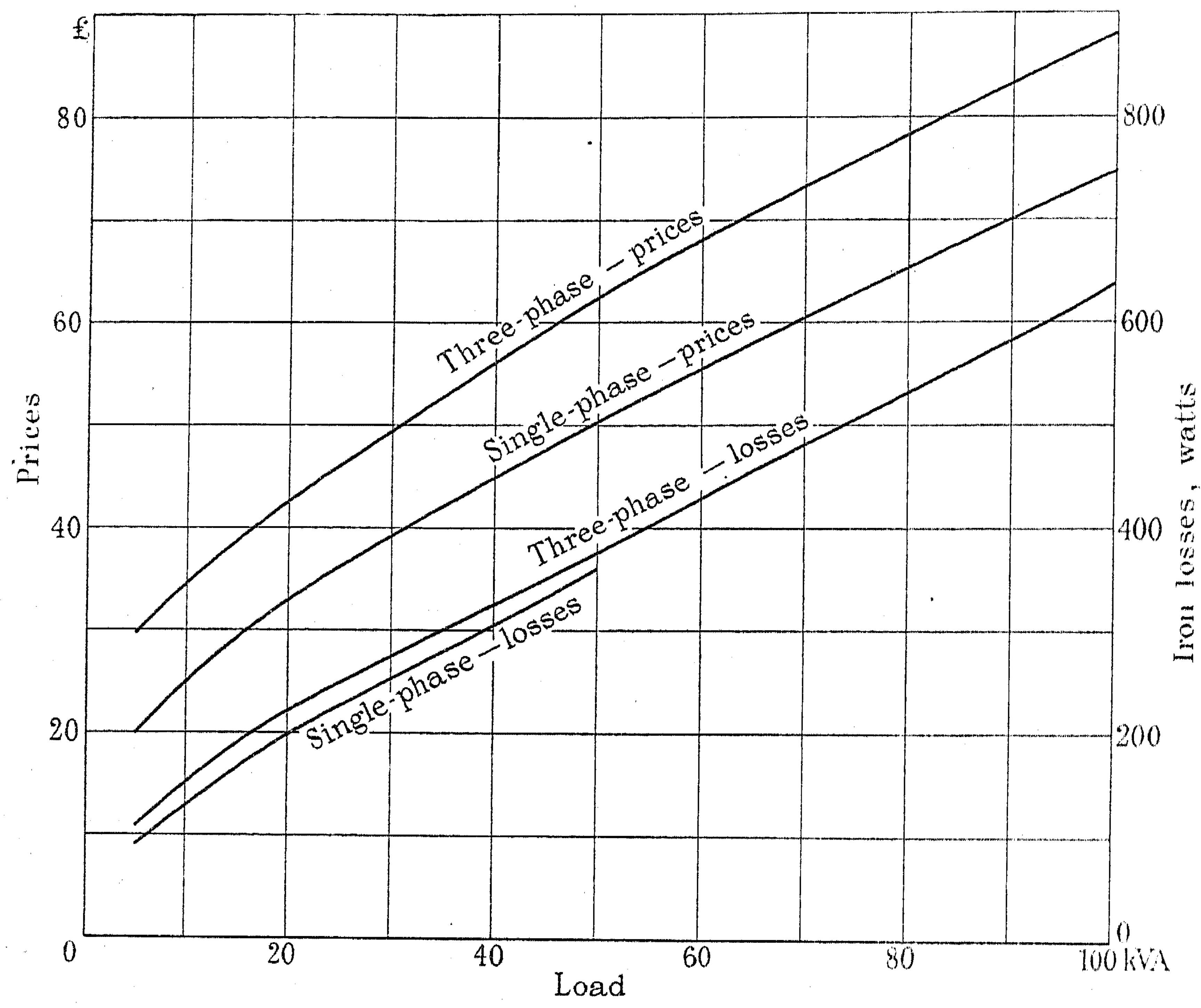


FIG. 10.—Price and loss curves for 3-phase and single-phase transformers.

As the vertical type of insulator is very liable to be injured during transit and erection, and in subsequent repair work, it is suggested that the inverted type of insulator, which is also cheaper, should be adopted. The chief disadvantage of the latter type is that the connections between the transformer and the terminals are not under oil, with the result that a flashover may occur in the tank above oil-level. This difficulty has been overcome by extending the insulator, and using cambric-insulated tails between the terminal and the transformer results in an increase in the flashover value. Where the vertical type of terminals is used the spacing should be sufficient to prevent short-circuiting by birds, etc. Unfortunately, on the smaller sizes of transformers this is difficult to obtain. For 11 000 volts, 18-in. centres between terminals and at least 12-in. clearance between the line connections and earth should be provided.

Wherever possible, mechanical connectors for connecting outside tails should be adopted. The low-tension terminals should be brought out at the side of the tanks to facilitate connection to the overhead lines.

(7) Low-Tension Distribution Lines.

The question whether 3-phase 4-wire distribution or some alternative system such as single-phase 3-wire distribution should be adopted now comes under consideration. In the case of 3-phase distribution a more expensive high-tension line, high-tension fusegear, and transformer are required. The l.t. 3-phase distribution line is not only more expensive but it is also more conspicuous, balance is more difficult to obtain than with single-phase 3-wire systems, and there does not appear to be any great advantage over single phase when weight of copper for weight of copper is concerned. For a distribution network in a small town where there are a large number of potential consumers and where underground cables can be justified as an economical proposition and also on account of amenities and the difficulties likely to be encountered in serving both sides of a wide street from an overhead distributor, a 3-phase system is preferable. For the smaller villages and more sparsely populated areas, there is much to recommend the adoption of single-phase 2-wire or 3-wire distribution.

Table 7.

	Single-phase	Three-phase
	£	£
11-kV line	90	127·5
Transformer (erected) ..	33	43.0
Fusegear (erected) ..	8	11·5
Service	6·5	11·5
	£137·5	£193·5

Moreover, not only are 3-wire distribution lines much neater and less conspicuous but also the clearance to buildings and Post Office circuits is more readily obtained and the size of poles and number of stays at angles are reduced. Post Office cradle-guards are reduced in size, giving a more pleasing appearance.

With the exception of the increase in cost and the starting difficulties of single-phase electric motors, single-phase 3-wire distribution has no apparent drawbacks, and as there are few motors used in rural areas of sizes greater than 5 h.p. the additional cost to the consumer is outweighed by other advantages, such as the reduction of distribution costs. Table 7 gives the costs of supplying a farm ½ mile distant from the nearest point of supply.

In addition to an initial saving of £56 with single-phase, the running costs are less on account of the lower iron losses of the transformer.

The comparative costs of single-phase and 3-phase motors (1 000 r.p.m.) complete with air-break starter fitted with no-volt and overload release are as given in Table 8.

Assuming that a 1-h.p. and a 5-h.p. motor were installed, single-phase motors would cost £15 8s. more than 3-phase motors.

Wood poles are still favoured in spite of the efforts which have been made to popularize other types of supports, and there is no alternative to the use of copper as a conductor. On account of the relatively high impedance of low-tension overhead lines, the size of conductor should be kept as large as possible, compatible with mechanical design and appearance, a 0·10-sq. in. (7/·136) stranded conductor being the maximum size permissible on account of the appearance and the difficulty in staying at angle positions. The conductors are supported in shackle insulators fixed to the pole by means of galvanized clevis and through-bolt, all the steelwork of which is bonded together by means of No. 8 S.W.G. tinned copper wire. This type of fitting can be used throughout for intermediate, angle, section, terminal, and tee-off positions, with the result that erection costs are reduced, as pole drillings are all the same, and handling, storage, etc., are much simplified. Not only is this type of construction easy to erect, cheap, and simple, but it also simplifies service connections.

Table 8.

Size of motor	Three-phase	Single-phase (230 volts)		
	Squirrel-cage	Split-phase. ·25/30 % full load starting torque	Condenser. 45 % full load starting torque	Condenser. 150 % full load starting torque
h.p.	£ s.	£ s.	£ s.	£ s.
1	8 4	11 3	16 7	17 5
5	13 15	21 11	28 16	36 17
10	19 1	31 10	54 4	54 4
15	23 4	38 7	69 0	69 0

It has become the general practice to use British Standard medium-size poles, although with straight-line work the calculated size may be somewhat less. Consideration should, however, be given to the side-loading due to overhead service lines.

British Standard heavy poles may be found useful for certain angle positions, but these are ugly for street work and create an obstruction unless sheltered positions can be found. Generally speaking, wood poles are unsuitable for unstayed angle positions. Every care should therefore be taken when surveying a route to ensure that stay positions can be obtained at angles.

The position of all poles should be carefully chosen with a view to causing the minimum of obstruction to pedestrians, and should be placed at the back of the footpath. This unfortunately results in increased heights of poles or the use of extended brackets to give 6-ft. clearance to buildings.

Poles are set to a normal depth of 5 ft., but where heavy angles or bad ground is encountered a greater depth or a kicking-block should be provided.

Conductors should be confined to two sizes, viz.

0·06 sq. in. (solid) and 0·10 sq. in. (stranded), the neutral conductor being of the same section as the phase conductors. Any conductor less than 0·06 sq. in. will sooner or later give rise to excessive voltage-drop, and should not be encouraged. The limitations of low-tension overhead distribution will be appreciated from Fig. 11 and, generally speaking, the radius of a low-tension distribution should not extend beyond $\frac{1}{4}$ mile.

Although the Commissioners' Regulations allow a factor of safety of 2, invariably the conductors are not erected to this tension, a factor of safety of $2\frac{1}{2}$ to 3 being given on account of the numerous angles to be met with in village distribution schemes. Conductors are only pulled up to the maximum permissible tension when a line is straight or where suitable stays can be attached at angle positions.

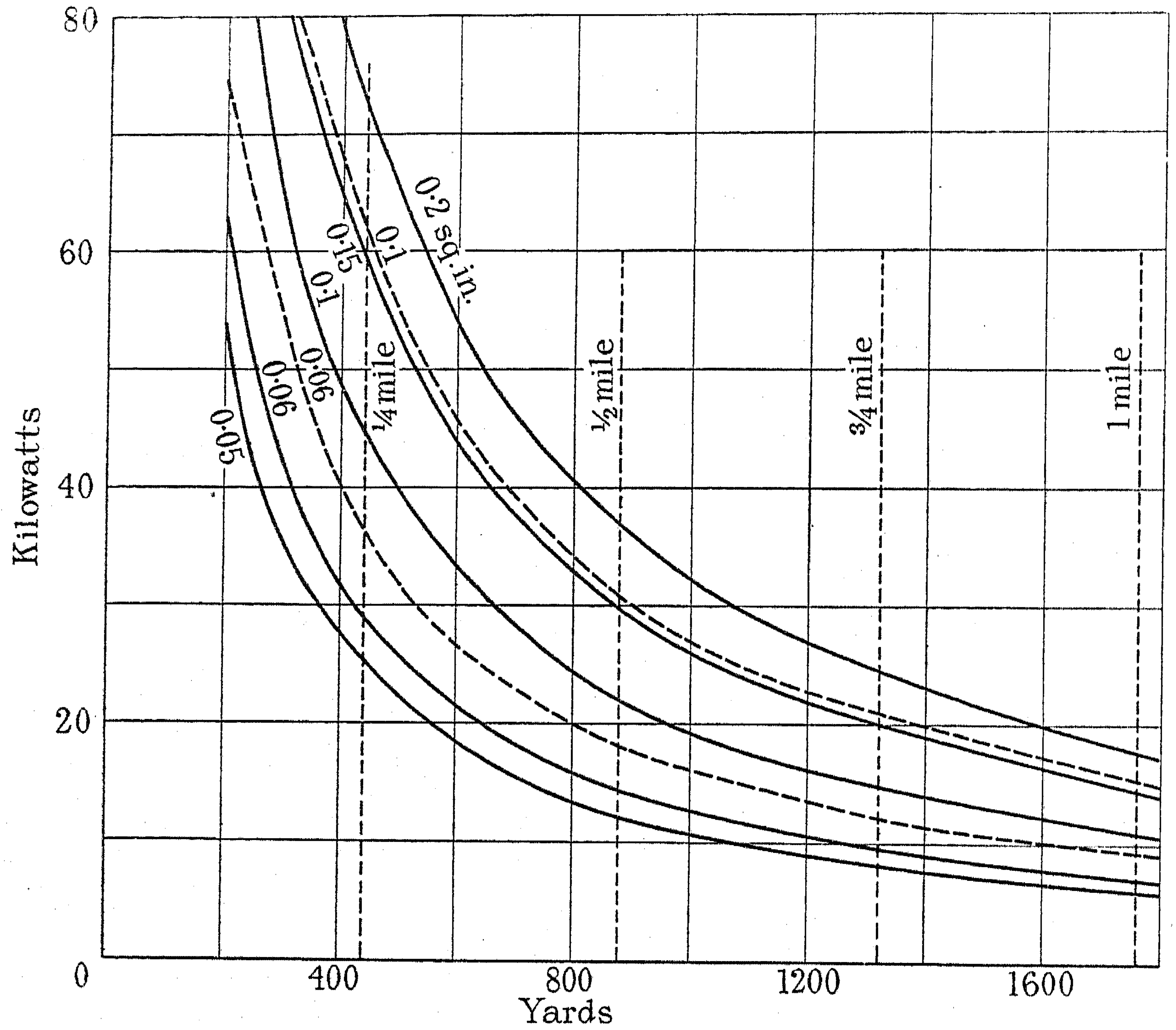


FIG. 11.—Load/distance curves for 400-volt 3-phase balanced load, allowing 4 per cent voltage-drop at 0·95 power factor.

L.T. overhead line, 12-in. spacing (full-line curves).
For single-phase 3-wire divide by 1·5.
For single-phase 2-wire divide by 6.
Underground cable (dotted-line curves).

The spacing of conductors of low-tension overhead lines has gradually been reduced from 2 ft. to 9 in., and it is found that with this spacing and with the conductors in a vertical formation no trouble from clashing is experienced with spans up to 150 ft. Not only does this result in reduced impedance but a much neater type of construction is obtained, particularly where 5 wires have to be erected. There is also a small saving in the height of pole.

Other types of insulators and methods of supporting conductors are in use, such as the Aylesbury insulator and the Callender–Brown insulator, each of which has its merits and presents a pleasing appearance, but their adoption must rest with the distribution engineer's ideas on this subject.

To complete the appearance of the line a spun aluminium finial will be found cheap, easy to fix, durable, and secure against dislodgment.

The protection of Post Office circuits adds to the cost of distribution lines and it is invariably found that the erection of a split-neutral guard where the Post Office lines cross under the power lines, or the erection of a dummy neutral on the top when the Post Office lines cross above the power lines, is a cheaper form of protection than insulating the power conductors. Where only one or two pairs of Post Office wires are involved, it is frequently cheaper to ask the Post Office to insulate their circuits. The costs of these guards, say 150-ft. spans, are as follows:—

2 × 0·05-sq. in. split neutral	£5 8s.
2 × 0·029-sq. in. split neutral . .	£4 6s.
0·029-sq. in. dummy neutral	£1 16s.

Average cost of insulating one Post Office circuit (2 wires) approximately 150 ft.: £1 5s. 6d.

Stays consisting of 7/8 S.W.G. (45-ton breaking stress) galvanized stay wire with $\frac{3}{4}$-in. diameter stay rods are generally used. It is suggested, however, that 19/10 S.W.G. stay wire with a 1-in. diameter stay rod provides an alternative; 19/8 S.W.G. stay wire should not be used for low-tension work, as stay insulators will not withstand the compressive load and an unsightly job is obtained. The present-day erection costs per mile of low-tension overhead lines, minimum size of pole 28 ft. × 8½ in. diam., with copper at £40 per ton (electrolytic wire bars), are as follows:—

4 × 0·10 sq. in.	..	£470
3 × 0·10 sq. in.	..	£390
2 × 0·10 sq. in.	..	£310
4 × 0·06 sq. in.	..	£370
3 × 0·06 sq. in.	..	£310
2 × 0·06 sq. in.	..	£250
2 × 0·06 sq. in.	..	£230 (26 ft. × 6½ in. pole)

For low-tension supplies to isolated premises where only 2 wires are required the British standard size of light poles is used and the ornamental finial is replaced by a zinc roof. The depth of pole setting is reduced to 4½ ft.

(8) SERVICES.

It is strongly recommended that, on account of the difficulty in obtaining adequate earths in rural districts, an "all insulated" service, including lead-in, cut-outs, meters, etc., should be used.

After many experiments the cheapest and neatest type of service has been found to be the "open wire" type, with two insulated V.C.J. conductors, or, if the cost is to be kept to an absolute minimum, the phase wire only need be insulated, the neutral being bare. For the sake of standardization the same type of clevis and insulator as used on the main lines are used for terminating the conductors on the house. The lead-in cable is twin compound-rubber weatherproof-insulated, braided and compounded overall. The cable is fixed to the wall either by means of non-ferrous clips or by porcelain cleats.

Although porcelain lead-in tubes are frequently used, these are difficult to fix and the entry of the cable is somewhat conspicuous. The author favours the lead-in of the above type of cable without any protection other than the cable being taped with two layers of bitumen tape where it passes through the wall. Every advantage should be taken of window sashes and door frames, and it is almost invariably found that the position of the cut-outs on the consumers' premises lends itself to the lead-in being taken in through the door frame.

The following standard sizes of services are adopted, and the cost of installing a 30-ft. service is given:—

0·0145 sq. in. (7/·052):—£1 13s.
0·0225 sq. in. (7/·064):—£1 15s.
0·04 sq. in. (19/·052):—£2 3s.

Three-phase 4-wire overhead services are only installed where a 3-phase power supply is required, in which case a similar arrangement is adopted.

Group and Sub-services.

To reduce the number of overhead service lines to a minimum it is desirable to loop from one consumer's premises to the other, either by means of extending the existing cable on the outside wall or by looping through the interior wall.

When there are several houses to be dealt with it may be necessary for a 0·04-sq. in. or 0·06-sq. in. 2-core cable to be run along the outside of the building, and for the service cable to be connected to this by means of a junction box. These junction boxes are also of the "all insulated" type and are filled with a plastic compound to prevent the ingress of moisture.

This method of distribution along the outside wall of buildings has solved many difficulties and overcome objections to overhead lines. The costs are as follows:—

0·04 sq. in. (19/·052), 2-core:—£203 per mile
0·06 sq. in. (19/·064), 2-core:—£267 per mile

Unless special circumstances demand it, 4-wire distribution should not be used as the work becomes conspicuous and service jointing difficult. It is found that 4 wires are seldom necessary.

Where street lighting is required a 3-core cable with a 7/·036-in. street-lighting core is used, together with the same type of tee box.

This method of distribution can be fed either from an overhead or from an underground distribution network.

(9) CONSUMERS' INSTALLATIONS, APPARATUS, AND EARTHING.

A study of rural electrification cannot be considered complete without reference to the installations on consumers' premises, as difficulties are encountered in rural areas which are not appreciated by the engineer who is accustomed to distribution systems in populous districts. The chief difficulty lies in the ability to obtain a low-resistance earth when large gravitation water supplies are not available. This question gives rise to the controversial subject, whether to "all insulate" or to "earth." The author is of the firm opinion that for rural distribution work the "all insulated" system should be adopted. The only drawback is the use of cookers and other domestic apparatus, such as wash boilers, washing machines, etc., which are installed in kitchens and sculleries which frequently have stone floors. If it were not for this apparatus, particularly the cooker, which is a most desirable and efficient piece of apparatus to install in a rural distribution scheme on account of its revenue-producing characteristics, the difficulties could easily be overcome as suggested by the author; but, as it is highly probable that all cottages will ultimately be equipped with a cooker, the question of earthing or some alternative means of protection must be faced.

Earthing Electrodes.

With a view to obtaining some further information on the type, length, and depth of setting, etc., on an electrode, and its bearing on lowering the earth resistance, the following experiments were carried out by the author:—

(*a*) Galvanized-steel tube (5 ft. × 2 in.) driven vertically into earth composed of sand and gravel. Resistance 300 ohms.

(*b*) Galvanized-steel tube (5 ft. × 2 in.) laid horizontally 18 in. deep in fertile soil and sand. Resistance 210 ohms.

(*c*) Galvanized-steel plate (18 in. × 18 in. × $\frac{1}{2}$ in.) buried vertically and at a depth of 2 ft. in fertile soil. Resistance 210 ohms.

(*d*) Galvanized-steel plate (18 in. × 18 in. × $\frac{1}{2}$ in.) buried horizontally at a depth of 2 ft. in fertile soil. Resistance 210 ohms.

(*e*) Copper strip buried horizontally at a depth of 18 in. in fertile soil.

1 in. × $\frac{1}{8}$ in. × 12 ft. Resistance 120 ohms.
1 in. × $\frac{1}{8}$ in. × 36 ft. Resistance 44 ohms.

(*f*) Stranded copper wire (7/·044 sq. in.) 54 ft. long, buried horizontally at a depth of 12 in. in fertile soil. Resistance 47 ohms.

(*g*) Copper welded rod (8 ft. × $\frac{3}{4}$ in.) driven vertically into sandy soil. Resistance 350 ohms.

Since all these values were much too high for adequate earthing, further experiments were carried out using perforated galvanized tubes which could be treated. Results of experiments with these tubes are shown in Table 9. Comments are as follows:—

TABLE 9.

Resistance of Various Types of Electrodes.

	Description of electrode							
	1	2	3	4	5	6	7	8
	2-in. diameter galvanized tube driven 5 ft. Holes at point of tube only. Hand-treated with brine	As 1, but treated by force-pump	As 2, but holes drilled throughout length	2-in. diameter galvanized tube 5 ft. long buried horizontally at 18 in. depth. Treated with brine by force-pump	As 4, but $\frac{3}{4}$-in. diameter galvanized tube 12 ft. long	As 5, but tube in form of circle 4 ft. diameter	As 5, but tube in form of circle 9 ft. diameter	As 6, but 2-in. steel tube
Before treatment ..	300 +	300 +	300 +	210	205	105	220	160
After—								
1st treatment ..	250	190	85	58	120	60	105	55
2nd treatment ..	200	160	48	33	95	55	95	50
3rd treatment ..	150	140	45	25	90	52	90	48
4th treatment ..	110	100	45	25	85	50	82	48
5th treatment ..	84	70	45	25	80	47	75	48
6th treatment ..	81	55	45	25	70	47	75	48
6th–15th treatment	68	45	45	25	65	47	75	48
16th + treatment..	50	45	45	25	65	47	75	48

(1) This experiment with the tubes perforated at the end only, and saline treatment by hand, reduced the resistance considerably but did not bring it below 50 ohms.

(2) Similar to (1), but treatment was carried out by force-pump. This method accelerated the reduction in resistance and brought the final resistance slightly lower, to 45 ohms.

(3) The tube in this instance was perforated throughout its whole length and the treatment was carried out as in (2). The resistance was reduced more rapidly, but the final resistance was not reduced below 45 ohms.

(4) The electrode employed was a perforated tube 5 ft. in length laid horizontally at a depth of 18 in. and treated as in (2). The resistance fell very rapidly and finally reached a lower resistance than the other electrodes, viz. 25 ohms. This would appear to be due to the electrode being buried partially in cultivated soil.

(5) A smaller section of tube (12 ft. × $\frac{3}{4}$ in.) was laid in sandy soil at a depth of 18 in. to ascertain the effect on the surface area of the electrode and to compare with (6). This type of electrode was inferior to the 2-in. tube driven perpendicularly into the ground.

(6) A tube (12 ft. × $\frac{3}{4}$ in.) was bent into a circle approximately 4 ft. diameter and buried at a depth of 18 in. The results were much better than (5), the final resistance being reduced to 47 ohms.

(7) To ascertain the effect of increasing the radius of the electrode, experiment (6) was repeated with a $\frac{3}{4}$-in. tube bent in a circle 9 ft. in diameter. This tube was laid under the same conditions and given the same treatment, but the results obtained indicated that there was no advantage in increasing the radius of the electrode.

(8) To ascertain the effect of increasing the size of the tube (i.e. the surface area), a 2-in. tube was formed into a circle 4 ft. in diameter, as in (6), and was laid under the same conditions. Although the first test showed a higher reading than that obtained under (6), the resistance dropped much more rapidly on subsequent treatment. This would indicate that by increasing the surface area the resistance is not appreciably affected.

The foregoing experiments, which were conducted in sandy soil, indicate that for practical purposes, i.e. for earth readings below 100 ohms, the size, shape, type, and depth of setting of an electrode do not materially affect the resistance in a given class of soil.

" *Electrolyte.*"

As the foregoing experiments proved that the resistivity of the soil was the principal factor in obtaining low-resistance earths, it was decided to experiment with various materials surrounding the electrode. These materials, for the want of a better word, will be called "electrolytes." There is another reason why the substance surrounding an earth electrode should be called "electrolyte," i.e. the electrodes when placed close together and joined in parallel appear to behave like an electric cell, a back-e.m.f. being set up when current is flowing to earth via electrodes. Probably when a method is found of "depolarizing" an "earth electrode" a simpler form of earth may be produced.

Holes 1 ft. in diameter were augured out in the same class of sandy soil and the "electrolyte" inserted into these holes with the electrode placed centrally. Table 10 gives the resistance obtained with various substances, the interesting features being:—

(1) That crushed coke was definitely of a lower resistance than other grades of coke.

TABLE 10.

2-in. diameter Tubes 5 ft. in length placed centrally in Holes 5 ft. deep × 12 in. diameter, with Various Materials packed round the Electrodes.

Material inserted	Resistance
	ohms
Coke-breeze lumps	220
Small coke	185
Riddled small coke	60
Peat	200
Salt	190
Salt and water	190
Phosphates	83
Phosphates and sand	70
Phosphates and salt	50
Salt and sand	80
Salt and peat	98
Salt and coke-breeze lumps ..	130
Salt and phosphates and sand	45
Soot	85
Sand and soot	190

(2) That salt in itself even when treated with water gave a very high resistance, but salt (or saline) mixed with other substances lowered the resistance considerably.

(3) Phosphates gave a comparatively low resistance. When mixed with sand the resistance was decreased, and with saline treatment the resistance was considerably reduced, this mixture giving the lowest reading.

In conjunction with these tests further experiments were carried out (see Tables 11 and 12).

From Table 11 it will be observed that there is no advantage in increasing the depth of coke (electrolyte) as it was found impossible to get below 60 ohms. This resistance was reached after 3 ft. of coke had been inserted. Table 12 indicates that the length or surface area of the metal electrode has little effect in reducing the resistance of an "earth."

In a number of the above experiments the material was removed from the hole and formed into a heap on the surface of the ground. The tube was then driven approximately 9 in. into this heap. The earth resistance obtained was the same as when the whole tube and material were in the hole. This proves that the surface area of the electrode is not important and that it is the "electrolyte" which is the effective medium in reducing the resistance. Moreover, there did not appear to be any advantage in increasing the quantity of the "electrolyte" after a certain resistance value had been reached.

TABLE 11.

2-in. diameter Tube 5 ft. in length placed in Hole 4 ft. deep × 12 in. diameter, and Riddled Small Coke Breeze filled into Hole.

Depth of coke in hole	Resistance of electrode
in.	ohms
6	105
12	84
18	70
24	65
30	63
36	61
42	60
48	60

Random Tests.

(*a*) In one district an earth plate (18 in. × 18 in. × ½ in.) was buried 6 ft. deep in the bed of a brook with the water constantly flowing over the top of the coke, which was brought to the surface. Every facility was given for the water to penetrate, yet a reading of 100 ohms was obtained.

TABLE 12.

Hole 4 ft. deep × 12 in. diameter filled with Riddled Small Coke Breeze, and 2-in. diameter Tube driven slowly into Coke.

Depth of tube in coke	Resistance of electrode
in.	ohms
6	60
12	60
18	60
—	—
—	—
—	—
48	60

(*b*) In another district, which was in a valley through which a river flowed, the following method was adopted. Two 18-in. square plates were buried vertically 3 ft. apart in a bed of coke (5 ft. × 3 ft. × 8 ft.) and thoroughly soaked with water. The resistance obtained was 17 ohms.

(*c*) Earth electrode (18 in. × 18 in. × ½ in.) buried 5 ft. deep in bed of coke gave a resistance of 60 ohms.

Private water-supply pipe adjoining gave 8 ohms. Electrode and pipe connected together gave 7½ ohms.

(d) Even where private water supplies are available difficulties occur, e.g. electrode at transformer gave a reading of 35 ohms, private water pipe at the consumer's premises 10 ohms. As the earth resistances at transformer and consumer's premises are in series the two added together, viz. 35 + 10, would only ensure that a 5-ampere fuse would blow. These circumstances suggest that the neutral should also be connected to the water pipe on the consumer's premises, as only by doing so can assurance be given that the fuses will operate in the event of a fault to earth on the consumer's installation.

TABLE 13.

Earth Resistances in Parallel Electrodes of 5 ft. × 2-in. diameter Galvanized Tubes driven 5 ft. in Sand and Gravel Soil.

Electrode resistance, ohms			Spacing, feet			Resistances in parallel, ohms	
1	2	3	1–2	2–3	3–1	Measured	Calculated
50	105		9			45	35
50	90		9			45	32
112	100		9			62	53
105	95		16			55	51
90	92		16			50	45
90	95		16			51	46
95	175		16			65	62
50	112		16			36	35
82	71		16			44	38
50	95		20			38	33
50	92		20			37	32
90	190		20			70	62
48	38		36			22	22
48	30		66			18	18
48	38	30	12	11	23	13	12½
50	105	95	9	16	16	35	25
90	92	190	16	16	16	45	37
90	95	210	16	16	32	43	39
90	95	175	16	16	32	42	37

Many cases were encountered which gave the most conflicting results.

These tests show that the treatment of an electrode with water will not reduce the resistance materially and that it is necessary to introduce a form of salt in order that the resistance of the surrounding body of earth may be reduced.

Spacing of Electrodes.

Experiments indicate that, according to the class of soil, the electrodes require to be spaced at certain distances before the law of resistances in parallel will apply, i.e. in sandy soil electrodes require to be spaced 15 to 20 ft. apart. In rocky soil spacing requires to be increased to between 30 and 40 ft. In a hilly district the initial resistance of each electrode was as high as 200 ohms, which after several saline treatments was reduced to 70 ohms and could not be further lowered. The electrodes, 6 in number, were connected in parallel and the total resistance was finally reduced to 13 ohms.

To reduce the resistance to a low value it is necessary to use several electrodes in parallel, but this method can become expensive and impracticable, e.g. a single driven electrode in sandy soil after saline treatment can be reduced to 45 ohms. To obtain an earth resistance of 2·8 ohms it would be necessary to install 16 electrodes approximately 15 ft. apart, i.e. over a distance of 80 yards if arranged in a straight line, or over an area of 20 × 20 sq. yards if arranged to form a square.

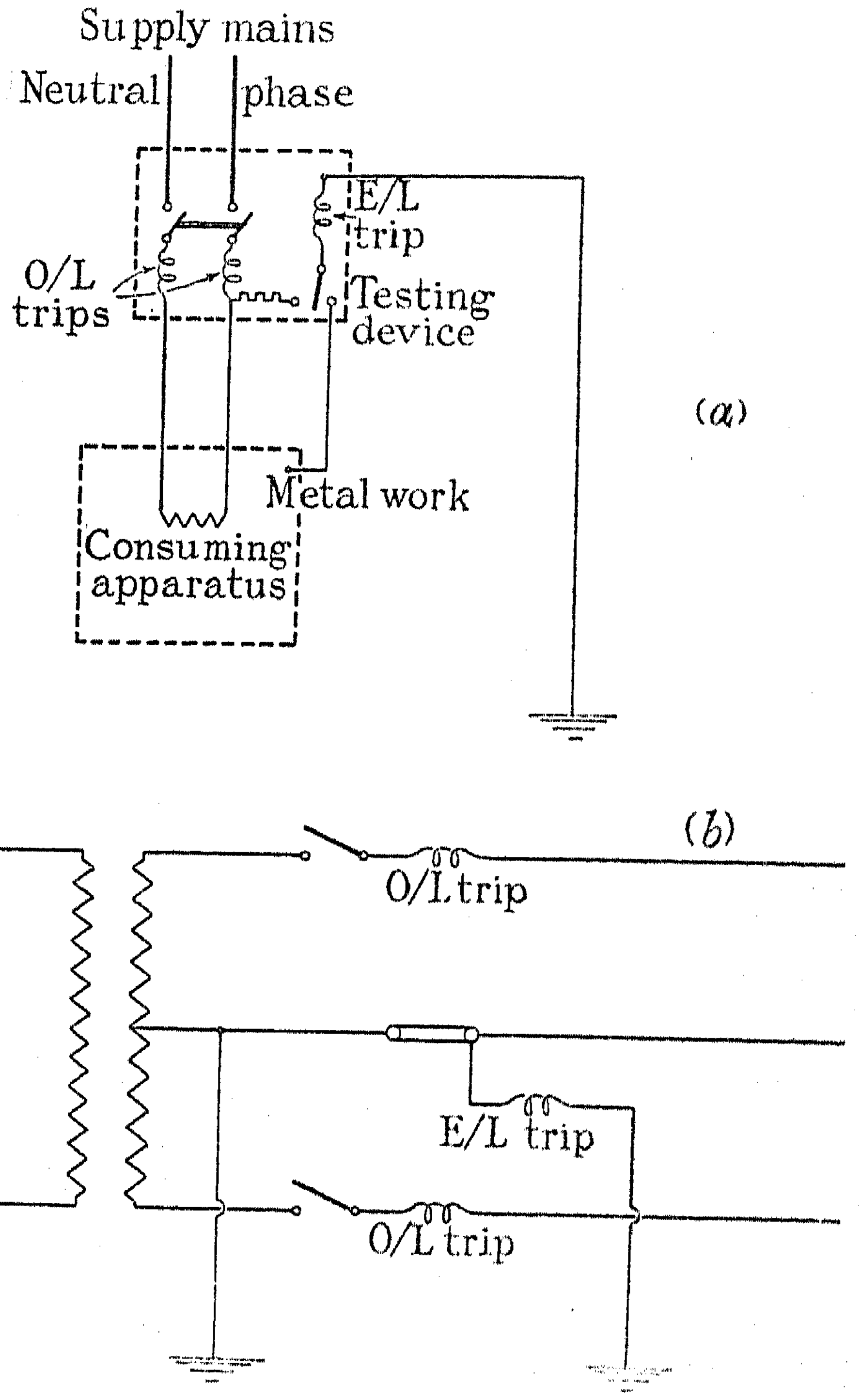


FIG. 12.

(a) Earth-leakage circuit breaker for consumers' premises.
(b) Earth-leakage circuit breaker for main distribution.

Results of tests taken with electrodes in parallel are shown in Table 13.

Summary of Results on Electrodes.

It would appear that no matter what type of earth electrode is employed under certain conditions it is impracticable to obtain a low-resistance earth. It is therefore suggested that in rural districts where public water-supply pipes are not available for earthing purposes, earth-leakage circuit breakers should be employed on consumers' premises to protect the installation and also at the transformer to protect the distribution network. A diagram of connections is shown in Fig. 12.

For consumers' installations, 15-ampere and 30-ampere single- and double-pole earth-leakage circuit breakers of British manufacture are available at prices ranging from 8s. 6d. to 30s. each. These will operate on 20 to 30 milliamperes, according to the impedance of the trip coil, the resistance of the earth electrode, and the inertia of the operating mechanism.

The general behaviour of these switches is satisfactory with earth resistances as high as 400 ohms. The type of driven electrode used should be selected for its mechanical and lasting properties, as the size does not materially affect the resistance and consequently the operation of the switch. It is suggested that an extruded copper rod 3 ft. in length, obtainable at a price of 2s., is satisfactory, care being taken to protect all earth wires and connections against mechanical damage or interference. An armoured corrosion-proof cable is now available and is strongly recommended.

With regard to the earth-leakage breaker for the control of distribution networks, these are equipped with overloads on each phase and the earth-leakage coil operates on a variable earth leakage 25 to 50 milliamperes at 50 volts. Care should be taken, however, to place the earth electrode connected to the earth-leakage breaker outside the " solid " earth zone, otherwise the switch will not operate *satisfactorily*. With this method adequate protection can be obtained and adjustments can be made to give discrimination between the consumers' and the main circuit earth-leakage trips.

(10) SYSTEM PROTECTION, ETC.

As expensive protective relays cannot be justified for rural distribution schemes, switchgear equipped with simple direct-acting trips shunted by time-limit fuses must be employed. Unfortunately, the usual type of tin-lead-alloy time-limit fuse does not always provide sufficient discrimination under short-circuit conditions, i.e. a remote fault could trip all switches back to the main substation, cutting off the supply to a much wider area than was necessary. To overcome this disadvantage experiments were carried out with various types of fuse elements, and fusegear manufacturers were approached on the subject. A time-limit fuse was produced which consists of a pure tin wire ½ in. to ¾ in. in length, soldered to copper tags and capable of being mounted in standard time-limit fuse contacts. By using nominal fuse ratings of 5, 7½, and 10 amperes, discrimination was obtained under the short-circuit conditions which would occur on a rural distribution scheme, i.e. the fuses were tested several times with currents as high as 80 amperes and the order of fusing was correct; thus with a current-transformer ratio of 30/5 the short-circuit kVA could exceed 10 000 kVA and adequate discrimination be provided. It will be appreciated that owing to the relative high impedance of overhead lines, transformer reactance, and/or earth resistances, a greater short-circuit capacity than this is not likely to occur, except close to the main substation, in which case discrimination is not required.

Although the feeders may be arranged for ring-main operation, unless expensive protective relays are installed these rings cannot be operated permanently on a closed circuit. This arrangement would be a considerable disadvantage in city or urban networks, but for rural distribution work it is found satisfactory.

For branch and spur lines, fuses are generally used for protection, their time-limit characteristics being such that they operate before the main-line oil circuit-breakers.

Lightning.

The cost of installation of lightning arrestors or surge absorbers is prohibitive for rural distribution schemes as, to be effective, they would require to be installed at numerous points. In any case there is no assurance that complete protection will be provided, and therefore recourse must be made to a simpler form of protection; this can be provided by suitable grading of insulators. On apparatus where a failure would be of serious consequence, viz. transformer, dividing box, and switchgear insulators, etc., the flashover value should be increased at least 10 per cent. It has been found that with 11-kV overhead-line insulators of suitable design the induced charge will spill over without disastrous consequences to the insulators. In a few cases the sheds have been shattered, but it is very rare that a line is put out of commission until the insulators are replaced.

As is well known, failures due to lightning rarely repeat themselves. It would therefore seem to be beyond man's ingenuity to guard against all possible failures, and consequently it does not appear worth while to install costly apparatus to avoid an interruption to the supply which may be of very short duration.

[The discussion on this paper will be found on page 812.]

Discussion before the Transmission Section, 15th May, 1935, on the Papers by Mr. Dean (see page 749) and Mr. Ross (see page 797) respectively.

Mr. W. Fennell: With regard to Mr. Dean's paper, I suggest that, apart from the sag tables, considerable caution should be exercised—particularly by chief engineers of undertakings—in allowing the tables to be used indiscriminately for line design. To put the matter in another way, I think no one should be allowed to use these tables who is not capable of working them out, because one is liable to get into a habit of using tables blindly according to a rule-of-thumb method. As some of the diagrams are fairly complicated it is quite easy to make a mistake in obtaining data from them. None of us has more than seven or eight different designs on his own system, and these should be carefully worked out. I hope also that there are no mistakes in these tables, and that they have been submitted to the Electricity Commissioners' staff to make quite sure that they will be accepted. For instance, the data in regard to pole foundations are, I think, very dubious. The subject of pole foundations is one which can only be settled satisfactorily in the actual locality, taking into account the density of the soil. The author speaks of raising the fulcrum a foot or two; but the position of this point is fixed by the soil. It depends to a very great extent upon the relative densities of the soil near the surface and of that lower down. These are variable, and I do not think the matter is susceptible to being dealt with by means of a graph.

I should certainly have liked to have seen, in preference to most of these graphs, the ones which Mr. Dean unfortunately had not time to plot, which are referred to in the Conclusion to his paper—graphs showing voltage-drops at different spacings and loadings for various classes of high-voltage conductors. These are difficult to work out, but would be of considerable use. The sag tables contained in the paper are most useful, and should be in the hands of everyone concerned.

With regard to the paper by Mr. Ross, there are one or two questions which I should like to ask. On page 798 he refers to wayleave rentals commuted to 18 years' purchase, and I should like to ask why he considers that a wayleave should be cut down to this basis, which is rather low.

In Table 2, Mr. Ross gives figures for the cost of laying underground mains. I should like to deprecate the publication of these statements indicating that the cost of underground work can approach the cost of overhead work. If these figures fall into the hands of laymen, they may say "We are told that the cost of a low-voltage overhead line is over £400 a mile, and here we find figures in this table of £482 and £554 for underground mains." These latter costs are really double those of the corresponding overhead lines, as the cases where one can get a shorter route underground compared with overhead are very few. I think it is misleading to give these figures without expressing that point of view.

With regard to the question of Post Office costs, Mr. Ross has stated what many of us have found over a considerable period of years, namely that the cost of protecting the Post Office is a very great handicap, especially in connection with high-voltage lines. The Post Office does eventually relent and allow a somewhat cheaper form of construction to be carried out, but it does not even apologize to those undertakings which have been forced to waste their money in past years. It is unfortunate that pioneers have to pay heavily when the Post Office overestimates the standard at which safety can be obtained.

With regard to single-phase as compared with 3-phase working, I cordially agree with Mr. Ross. We ourselves have carried out a great deal of single-phase distribution in the Mid-Cheshire area, even more cheaply than he claims; because by earthing one of the phases of the 3-phase system instead of the neutral point, high-voltage insulators and fuses need be fitted to one pole only; and we have roughly halved the cost of the accessories, which enables us to go farther at the same price.

I am surprised to find that Mr. Ross has apparently not heard of the Overhead Lines Association's standard specification for pole transformers, which was published 2–3 years ago, and is in use. This specification has standardized the sizes, and gives a formula which enables one to choose the losses which give the minimum cost under difficult conditions.

With regard to earthing, figures over 2·5 ohms can rarely be satisfactory for earthing the source of a low-voltage supply. As none of the figures given by Mr. Ross is less than 17 ohms, it is clear that earthing is useless in his district for that purpose. Figures up to 200 ohms are satisfactory, for high-voltage circuits, especially if used in connection with protective gear.

I should like to ask for confirmation of the figures given in Section (8) of his paper for the cost of the insulated overhead behind-the-house method for multiple services. The figures are £203 and £267 per mile for sizes of 0·04 sq. in. and 0·06 sq. in. respectively. These conductors have to be carefully fixed at fairly frequent intervals along the house backs. I do not know the cost of the conductor or its class or quality, but it needs to be good. It is exposed to the sun, and to the weather to some extent, and I can hardly think that Mr. Ross could do such work at an inclusive cost of £200 to £250 per mile; at any rate, we have not been able to adopt the system in our area. We run aerial wires from chimney to chimney, insulate the live wire only, and so reduce the cost.

I agree in general with the views of Mr. Ross on lightning protection. It is rather awkward to be compelled to admit that we have not yet been able to obtain a design at a reasonable price which will protect our lines, and particularly our apparatus, from injury.

Going back for a moment to the question of single-phase work, I should like to mention that nearly all farm apparatus is designed to work with petrol engines, which have, as it were, a "negative" starting torque, i.e. one has to turn the handle or do something of that kind. In other words, there is always a fast-and-loose pulley, so that the objection of single-phase motors not starting under heavy-load conditions is not important.

Mr. P. J. Ridd: I do not agree with Mr. Fennell that the Post Office is unreasonable in regard to the protection of its circuits. If a design of guard is submitted that offers the same measure of protection as any standard design which we have at the moment, is as durable, and is less costly, the Post Office will be very glad to give it favourable consideration. There is evidence of this in the papers under discussion. I would suggest to Mr. Fennell that in this respect the Post Office is represented by its engineers, members of this Institution, who have every desire to see an extension of electrical power distribution.

With regard to Mr. Dean's paper, I am very interested in the graphs relating to the values of earth resistance and the depth of setting of poles; although they may not perhaps be accepted as more than useful guides, they form a valuable addition to the published information on the subject. I may perhaps be permitted to bring to Mr. Dean's notice a recent paper by Mr. W. H. Brent* on "The Telegraph Pole," in which it is shown that poles should be planted so that the depth is a function of $d^{\frac{2}{3}}$, where d is the diameter of the pole at the ground line. With regard to Fig. 10, is it the practice in power distribution construction to use the auger or the bar and spoon to any great extent for excavating circular holes? Those tools are used very largely in Post Office work, and the economies obtained by their use and in the avoidance of the stepped hole are very considerable. In the erection of the poles we find the crane lorry a very useful tool when any considerable number of poles have to be erected on one route. The crane lorry is better than any other form of derrick of which we have had experience.

With regard to the paper by Mr. Ross, there is no reference in the section headed "Lightning" (page 811) to any protection for the consumer, and so far as I know it is not the practice of supply authorities to install lightning protection on consumers' premises. The Post Office, on the other hand, install lightning protectors on any lines which enter by overhead spans into subscribers' premises. The protectors are frequently damaged, and in general they serve their purpose in preventing further damage. I should like to know what is the experience of supply authorities of damage to consumers' premises caused by lightning.

In conclusion, I should like to ask Mr. Dean whether he has had any experience of joint construction for power-distribution and communication services, and whether he has any views as to the useful possibilities of such joint construction.

Mr. H. J. Allcock: It will generally be acknowledged that if underground cables can be justified on economic grounds, then they are preferable to overhead lines because of the greater security of supply ensured, absence of interference with amenities, and generally better electrical performance. I am therefore somewhat disappointed to see that Mr. Ross deals all too briefly with the cable problem.

At the end of Section (1) of his paper Mr. Ross refers to a mechanical excavator, which he suggests can be used economically only in the most favourable circumstances. Trench-digging machines have, however, been designed and built which are capable of operating even in very bad soils, such as heavy clays. Indeed, the only types of soil in which they are at a disadvantage are those where large boulders or very heavy tree roots are present. The normal size of trench suggested for rural distribution schemes is 3 ft. deep and 1 ft. wide, and such a trench can be mechanically excavated at the rate of 500 yards in a working day of 8 hours, allowing for the normal number of obstructions such as road crossings, hedges, and ditches. The cable drum is mounted on a caterpillar carriage drawn by a caterpillar tractor. This runs over the line of the trench, the cable being paid off from the drum into the trench as the tractor proceeds.

These advances in mechanization, reducing the cost of excavating and laying cables, have encouraged the development of a new type of 11-kV cable for rural electrification, to dimensions different from those given in B.S.S. No. 480. It is well known that rural lines are designed more on considerations of voltage-drop than on current-carrying capacity, and because of this fact the temperature-rises are negligible or very small indeed. A thickness of dielectric can therefore be used which would not be permitted for urban distribution, where the cable, on much shorter runs, is heavily loaded, and may have a temperature-rise as high as 50° C. The new rural cable is of the 3-core screened type with 0·05-sq. in. shaped conductors, and a dielectric thickness of 0·10 in. instead of the normal 0·14 in. given in B.S.S. No. 480. With the cable laid at a depth of 3 ft. there will be freedom from mechanical damage except in abnormal circumstances, since the maximum depth of normal working of the soil, even of deep ploughing, is only about 18 in. Armouring has therefore been omitted in order to reduce the cost and weight of the cable; and it is only necessary to protect the lead sheath from chemical corrosion, which can best be done by covering the cable with bituminous compounds divided into layers and held in position by means of tapes made of fibrous materials. A finish which has proved satisfactory, both on accelerated life tests and in service, consists of two paper tapes, one cotton tape, and one hessian tape, all impregnated in and served with bituminous compounds of suitable consistencies. A cross-section of the cable is shown in Fig. A. Its overall diameter is 1·36 in., and its weight is approximately 29½ cwt. for a normal factory length of ¼ mile.

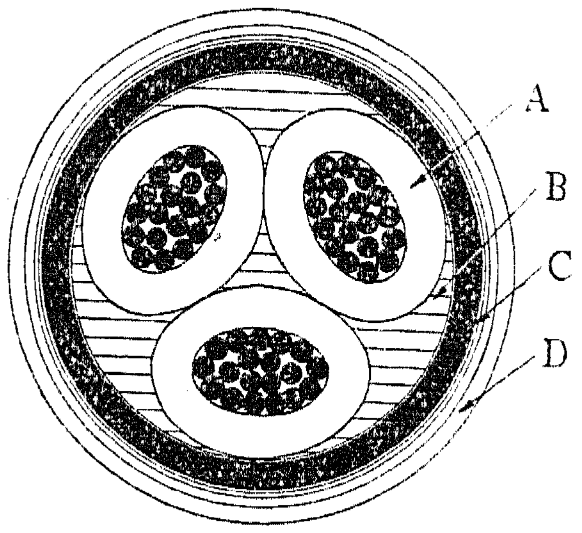


FIG. A.

A. Dielectric (0·10 in.).
B. Fillers.
C. Lead sheath (0·07 in.).
D. Protective covering (0·10 in.).

Fig. B shows the voltage/time-to-breakdown characteristic of such a cable. At 200 hours, where the curve has become asymptotic to a line drawn parallel to the time axis, the breakdown voltage is of the order of 43·3 kV, which represents a factor of safety of approximately 4 on the working voltage of 11 kV. A practical life test has also been made on a length of this cable in service. It was put in series with a 22-kV underground-cable line of much larger sectional area, so that not only was it overstressed in voltage but also overloaded in current.

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* Institution of Post Office Electrical Engineers, Professional Paper No. 154.

It is interesting to compare the voltage-drop of such a cable with that of the equivalent overhead line. When delivering 1 000 kVA at 0·8 power factor with a voltage of 11 kV over a distance of 15 000 yards, the voltage-drop for the underground cable is 6 per cent, while that for the S.C.A. overhead line is 8·05 per cent.

I am in agreement with Mr. Ross as to the difficulty of obtaining true comparisons of costs. The only satisfactory way of dealing with the problem is to make a comparison on an actual scheme, taking into account such questions as crop damage, tree cutting, wayleaves, etc. It is possible to state, however, that the special rural cable can be supplied and laid mechanically in soil of average consistency for a cost 30 to 40 per cent higher than Mr. Ross's figure of £364 per mile for the S.C.A. overhead line. This figure includes crop damage and wayleaves. In making a comparison the question of annual charges is of more importance than that of capital costs, and in this connection it may be noted that in Holland, where rural electrification is highly developed, the life of a cable is taken as 60 per cent longer than that of an overhead line. It is suggested that the advantages of the cable, together with its longer life, more than compensate for its greater capital cost, and make it worth consideration for schemes of rural electrification at 11 kV.

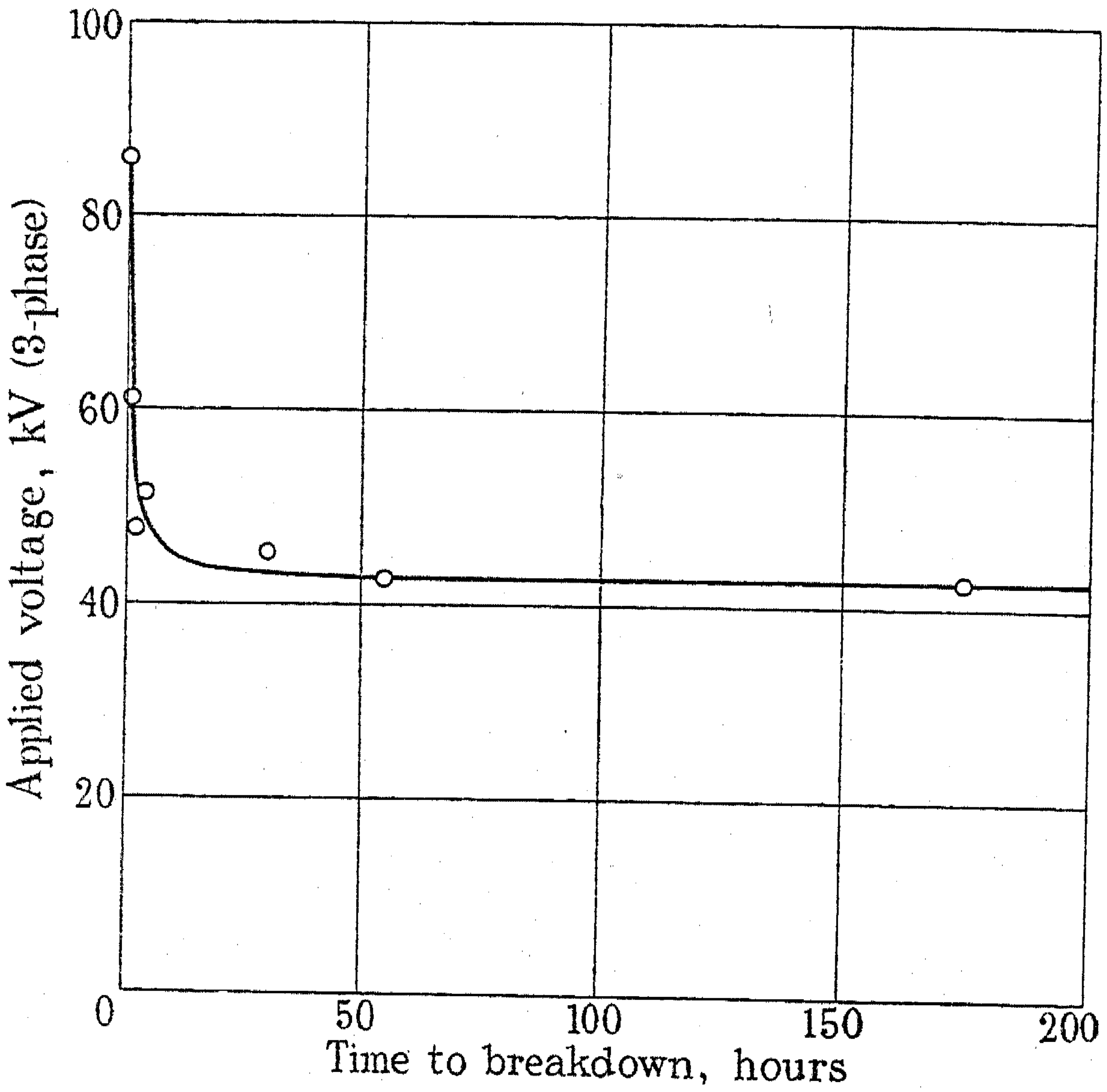

Fig. B.

Mr. P. Butler: The question of earthing which Mr. Ross mentions is of great importance, and it would be interesting to know what his experience is in regard to this matter, because the general consensus of opinion amongst supply authorities is that there should be an overhead earth wire. Some of the authorities consider that this is a definite protection against lightning. The experience of Mr. Ross would be particularly interesting because Dumfries is one of the worst areas in Great Britain so far as lightning is concerned.

It is stated on page 802 that one spur line of eight transformers is protected with one set of fuses. This is a striking tribute to the reliability of the modern transformer. No doubt each transformer is fused on the low-tension side; otherwise the one set of fuses will not give any protection on each transformer. In the event of a lightning storm a certain number of these fuses are usually blown and it would be interesting to know what, in Mr. Ross's opinion, is the reason for this. As far as can be judged, there are three or four reasons which may be put forward.

In the first place, it may be due to a breakdown in the transformer, but the fact that the transformer works satisfactorily after the fuses have blown and have been replaced proves that this is not the cause. There may be minute punctures in the insulation, which it is very difficult to see unless the transformer is examined very carefully and the coils are split up, but this is doubtful.

In the second place, the cause may be the high magnetizing current, because the voltage on the transformer which is struck by lightning reaches a very high magnitude. This is offset, however, by the fact that the frequency is of a very high order, which would tend to reduce the magnetizing current.

Thirdly, the cause may be the charging current due to the capacitance of the transformer. This has been calculated and agrees fairly closely with the results obtained in practical tests, and therefore this cause appears to be ruled out.

The only other suggestion one can offer is a flashover on the insulator, but traces of this are usually visible. It is quite possible that, with the high frequency of the lightning discharge, a flashover on the insulator may leave no evidence.

This is a most important subject, and it is in the interests of all concerned that a solution be found. This will only be made possible by the close co-operation of the supply authorities and the manufacturers concerned.

Mr. P. W. Laverick: Mr. Ross states on page 798 the minimum constructional cost of 11 000-volt lines as £302 per mile, and on page 800 he recommends sectionalizing every 4 or 5 miles with a sectionalizing switch costing £15 11s. (erected). I think that this figure is very much on the low side; for a reliable sectionalizing switch the figure should be nearer £25 (erected). I know of several instances where switches of the cheap type have been taken out and replaced by better switches within 2 years of being installed. In addition to being exposed to the weather and atmospheric conditions these switches are often mounted on wood poles, and therefore have to stand the stresses caused by the poles warping. It has been my experience on several occasions that switches of the cheap type have become very stiff in operation, owing to the contacts or bearings being out of alignment in consequence of warping of the poles or incorrect design of the switch. I think, therefore, one ought to be careful about economizing too much on the sectionalizing switches. Taking the cost of the line as £302 per mile, and allowing for a switch every 4 miles, a switch costing £15 represents about 1·25 per cent of the cost of the line, whereas a switch costing £25 represents 2 per cent. Thus the saving in first cost due to installing the cheaper switch is only 0·75 per cent.

Referring to the plug-in type of fuse, I do not care for this type, especially for outdoor 11 000-volt working, for three reasons.

In the first place, there is the possibility under heavy fault conditions of the fuse shattering inside the porcelain housing, which may cause an earth. If the fault consists of a cracked porcelain, an intermittent earth sometimes results. If it stands up in dry weather and goes down in wet weather, the fault is very difficult to locate.

Secondly, leakage inside the porcelain from the upper contact to the lower contact would find its way to the high-tension terminals of the transformer. In such an event the arrangement shown in Fig. 7 would be very awkward if the lineman withdrew the high-tension fuses and the low-tension fuses and assumed the transformer to be dead. I feel that there should not be any possibility of a leak from the high-tension line to the transformer terminals after the fuse has been withdrawn.

Thirdly, there is the question whether, with these plug-in fuses, one can detect from ground-level when a fuse has blown. I quite agree with Mr. Ross that this type of fuse is very easy to operate, but I should like to know whether it is necessary actually to withdraw a fuse from the housing and bring it to the ground in order to ascertain whether it has blown. If it is, it seems to me that this must increase the time lost in replacing the fuse, and this will mean financial loss to the supply authority and extra annoyance to the consumer.

Mr. T. C. Gilbert: Dealing with the earth-leakage circuit breaker for main distribution illustrated in Fig. 12 of the paper by Mr. Ross, the author rightly draws attention to the fact that the supplementary earth electrode must be located outside any likely sphere of influence from the main earth. There are, however, two other important points concerning the use of these switches that are not mentioned in the paper; one is that supplementary contacts should be fitted so that the circuit through the trip coil is broken when the switch opens, for the reason that the fault may originate in the transformer or its switchgear, and, if not isolated, may cause damage to the comparatively delicate trip coil. No damage will be caused the main earth if the fault current continues to flow over it, but the case is different with the supplementary earth circuit.

Another point is that the action of this switch should be slightly delayed, so that momentary transient potentials do not unnecessarily isolate the lines.

Mr. A. M. Pooley: On page 811 Mr. Ross mentions that he obtained satisfactory discrimination on h.t. switchgear used on a rural distribution scheme by employing inexpensive, specially made, time-limit fuses. I should be interested to know whether he has obtained similar satisfactory discrimination with h.t. power fuses. As an example, if a spur line protected by a 15-amp. fuse feeds a transformer protected by a 5-amp. or 10-amp. h.t. fuse, will a short-circuit or severe overload on the transformer be cleared by the h.t. fuse protecting the transformer, leaving the 15-amp. fuse unblown?

Mr. C. O. Boyse: Mr. Dean makes certain assumptions regarding the computation of pole foundations which are rather convenient from the point of view of design, but which I think are open to very grave suspicion. I speak from experience when I say that it is almost impossible to find any class of soil in which the resistance will vary directly with the depth. I should like to ask Mr. Dean what he takes as the criterion of failure of pole foundations; does he mean the complete collapse of the pole, or is he working on some arbitrary angle of heel? If he is thinking in terms of complete collapse, I imagine that the application of two-fifths of the assumed collapsing load—the working load corresponding to his assumed factor of safety of 2·5—would cause such a permanent deflection as to infringe the Commissioners' regulations. I agree with Mr. Fennell on this point, that Mr. Dean has gone rather too far in his search for short cuts, and has introduced complications which were not there before. At present, pole foundations are designed rather by rule-of-thumb methods and by past experience, but such a procedure is, I think, in the circumstances far simpler and sounder in the long run.

Mr. E. S. Broadhead: I should like to deal with the point concerning the foundations which has been raised by Mr. Boyse. I have searched continuously for the last 5 years for some formula by which I could design pole foundations, and I have found none which is satisfactory. Apparently Mr. Dean has used the method, mentioned in one of the well-known textbooks, of having the pressure at the fulcrum equal to the allowable unit pressure multiplied by the depth; in other words, the pole on heeling over does not have a point of no stress at its neutral axis, but immediately develops its full stress at that point, which seems rather strange to me. By assuming that at the fulcrum there is no stress on the earth, given as an example when reading Fig. 4A, I conclude that the pole (a 12-in. diameter pole sunk 6·8 ft. in the ground) is capable of carrying a bending moment of 23 100 ft.-lb., instead of 31 500. This means that in the case of this pole the factor of safety is only 1·83 instead of 2·5. While this may seem important it does not matter much really, because this 1·83 is only the factor of safety against keeping the pole erect. If the pole has moved over some distance, the condition is then quite different; the fulcrum will move up more towards the surface, and if the pole is to fail it has then to dig out a large area from the heel upwards. On moving over and getting a definite deflection it will stay there for some considerable time, because the earth will not fail rapidly. The pole would move over if the load were allowed to remain, but, as the load is only a gale, it will only be a few hours before the pole can have some attention, and it can then be pulled back into its proper position. The factor of safety against immediate total collapse is considerably more than the 2·5 required.

Although the risk of the pole heeling over is not important in the case of wood poles, which can easily be corrected, it is of some importance in the case of a very substantial concrete pole. I have in mind a line of about 900-ft. span in places, carried by concrete poles about 2 ft. in diameter at the bottom. In a case such as this it would be impossible to correct a pole if it did lean over, and therefore for an important line it is a little risky to use the author's tables. The latter are, however, quite good for wood-pole lines.

Mr. R. F. Markham: Dealing with Mr. Dean's paper, it is interesting to find (page 791) that the author is able to describe spans of 450–600 ft. as "medium spans"; this shows the tremendous advance which has been made in the last 6 years.

Turning to the paper by Mr. Ross, it is important that caution should be used in adopting the costs quoted by the author. The line costs, for example, must depend on transport, access conditions, contours, subsoil, and, more important still, on the rough-labour rate which engineers have to pay. The last item is very important, because some engineers will be paying 10½d. per hour for rough labour and others 1s. 1½d.; this gives at the outset a difference of about 30 per cent in the erection costs. It is therefore difficult to make use of the author's figures without a knowledge of the area to which they apply. Furthermore, I take it that these costs are really averages for large construction programmes, and it is important to realize that for short line extensions such prices are not likely to be achieved, because of the relatively heavy costs of terminal poles and special equipment for dealing with obstructions. Such equipment is shown in this slide. (Mr. Markham here exhibited a lantern slide showing a suspension angle pole or "flying angle" pole on a concrete-pole line, with the insulators drawn out to a direction approaching the horizontal.) The alternative construction for such a position would be straining insulators in both directions, and this would mean that the insulator costs would be doubled.

On page 798 it is stated "It is the author's opinion that S.C.A. conductors should be as satisfactory as copper conductors, provided a galvanized soft-iron wire is used as a binder. Soft aluminium binders are most unreliable. . . ." There is no need for any material but aluminium to be used on S.C.A. lines if stirrups are used made of half-hard-drawn aluminium of suitable size, say No. 2 S.W.G., and they are placed round the neck of the insulator and bound to the conductor by a large-size soft aluminium binding wire (No. 9 S.W.G.). If this practice is adopted, I am sure the author will not be troubled with broken binders. I agree that an ordinary binder of soft aluminium without some form of stirrup will lead to failure. Soft-iron wire should never be used in such circumstances.

With regard to the question of earth wires, I think I ought to say that continuous earth wires should be recommended and ought to be used wherever possible.

At the bottom of page 798, speaking of spur lines, for which he recommends a galvanized-steel conductor, the author says "little trouble will be experienced from clashing of conductors or breaking of binders." With the construction shown, involving 4 ft. 6 in. spacing, there should be no trouble with clashing conductors; the arrangement should be perfectly safe if the conductors are erected properly. With regard to broken binders, I assume that the author is again referring to galvanized-iron binders, and I do not think that they should be used, even on a galvanized-steel line. The cost of copper stirrup binders is very little extra, and I would strongly recommend them.

No reference is made in the paper to a vertical-type tandem switch, for use on spur lines or main lines, in which the 3-phase units are placed one below the other; this design gives a clear way at the back of the pole for the stays to take the spur-line tensions.

The paper states that open-type fuses are not satisfactory, but I must disagree with this; there are types manufactured in this country which are satisfactory, and one of these is shown in Fig. C. The fuse element itself is of open wire, but it is a patented construction and does away with the necessity for fine, small wires. Mr. Laverick mentioned the importance of having an indication that a fuse has blown; when this particular fuse blows, it acts as an automatic isolating switch, and the fuse tube swings down into a vertical position, as shown in the figure.

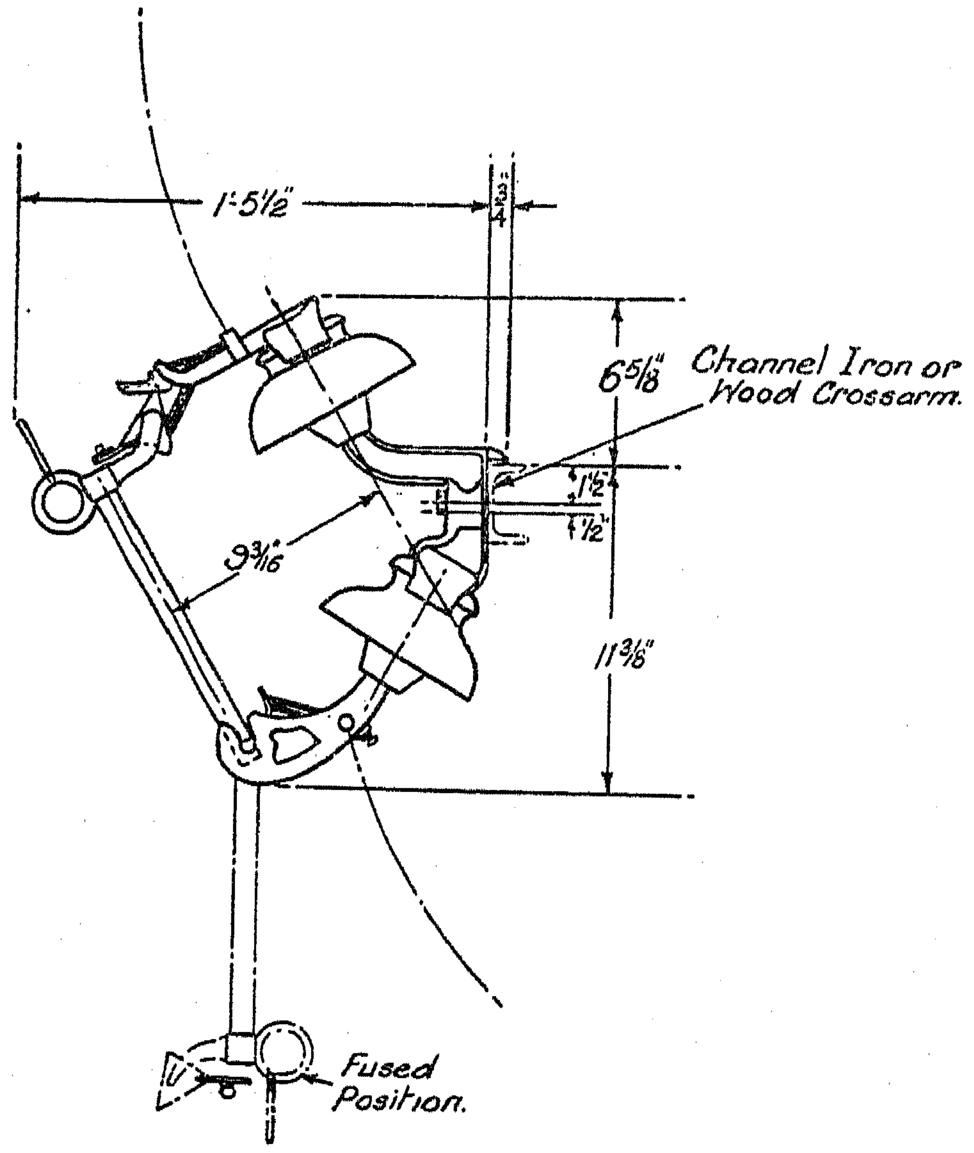

FIG. C.—Automatic drop-out switch-fuse, 11-kV size.

(*Communicated.*) At the top of page 800, reference is made to special rural cable. I should like to point out that several manufacturers are able to supply such cable and that it is suitable for laying in a trench excavated by hand, as well as in a trench excavated by mechanical means.

With regard to the disadvantage associated with oil switches, that it is necessary to install isolators for maintenance and inspection purposes; I should like to ask the author whether he has considered the use of live-line connectors, instead of isolators. These enable the oil switch to be disconnected without making the line dead. Their cost is small compared with that of the isolators, so that the disadvantage mentioned disappears.

In Fig. 5 there appears to be a clearance of about 5 in. between the sides of the poles and the outer tails passing under the switch-fuse frame. I suggest that this clearance is insufficient and that the tails should also be anchored to three pin insulators where they pass between the pole members.

I am interested to know that the author is erecting 50-kVA transformers on single-type poles. This is an advance on the usual practice, as the limiting size is usually taken as 35 kVA. Will the author inform me how the spur-line fuse rating is decided when eight transformers are taken off one spur line?

I should welcome his reasons for using solid copper for 0·06-sq. in. l.t. lines in preference to stranded copper. It is more difficult to handle the solid wire, to bend it accurately around insulators at make-off positions, and to get a good appearance free from slight bends.

On account of appearance I recommend that split neutrals for l.t. crossings over G.P.O. circuits be avoided. Split neutrals would be especially unsightly when used with the extended brackets mentioned by the author, and I have found P.B.J. conductors to be very little more costly.

Turning to page 807 ("Services"), I should like to know what method has been adopted for sealing the ends of the ingoing service cables. Also, has the author considered the use of the "Wonpeace" type of insulator instead of a clevis and shackle insulator for the wall end of the service? This type avoids the need for cementing into the wall, and the consequent delay in waiting for the cement to set.

I agree with him that distribution by cables on the outside walls of buildings will often be the solution to difficult situations and prove an acceptable alternative where objections exist to overhead lines. Where there are many deviations, trees, or G.P.O. wires, the cost of a wall distribution system may be even lower than that for an overhead line.

The results of the tests made on earth electrodes are very interesting, and in some cases surprising. For example, in test No. 8 of Table 9, the resistance of a 2-in. tube is given as 160 ohms, whereas in test No. 6 the resistance of a $\frac{3}{4}$-in. tube laid in the same manner is only 105 ohms. Can the author suggest a reason for the larger tube having the greater resistance? Similarly, by comparing test No. 4 with test No. 2, I notice that the electrode when buried horizontally 2 ft. deep has a lower resistance than when driven vertically 5 ft. deep. I should appreciate an explanation for this. It may be that the tests were made after a rainstorm following on a dry period, so that only the top soil was really wet. It would be interesting to know whether all the tests were carried out at the same time, and at what period of the year. Repeat tests made at a different period of the year might conceivably reverse the relative positions of the tests in the table. I should like to know the time-interval between the treatments mentioned in Table 9. In cases where low earth resistances are difficult to obtain I have found that a length of underground cable will reduce the resistance to a satisfactory figure. I know of instances where initially the resistance of the earth electrode has been of the order of 300 ohms but when the cable armouring has been connected up the resistance has been reduced to 3 ohms.

Mr. R. Borlase Matthews: I was very disappointed to hear Mr. Dean express the view that a wood-pole line was about 15 per cent cheaper than a line carried on fabricated or ferro-concrete poles. I assume that this figure is based on the same heights and the same spacings in each case. Where the fabricated and ferro-concrete poles score over the wood poles is where the height of the pole and the span are very much greater.

I should have thought that some of the data in Mr. Dean's paper could have been more effectively reproduced in the form of an abacus or nomogram.

I have a strong prejudice against drilling holes right through wooden poles, and hence I am very glad to see Fig. 9 (*b*), where a U-bolt is suggested for fixing kicking blocks; at the same time, I regret to observe that no alternative is proposed to through-bolts for the insulators shown in Fig. 8, (*a*) and (*b*).

Turning to the paper by Mr. Ross, I would point out that the difficulty from the farmer's point of view of having poles in the centre of a field is not so much the ploughing as the fact that they afford a very good nursery ground for growing weeds, resulting in the eventual distribution of the weed seeds over the fields themselves. I came across a farmer recently who had converted the lower part of a grid pylon into a sheep pen by putting a few hurdles round the base—a novel way of utilizing the wasted space under the pylon.

Like Mr. Fennell, I should like to ask Mr. Ross whether he has compared his transformer recommendations with those prepared by the Overhead Lines Association.

I do not think the last word has been said in the single-phase—3-phase controversy, and I should like to ask why it is assumed that the farmer requires only a 1-h.p. and a 5-h.p. motor. It seems to me that if only the farmer is led along the right lines he will utilize a great many more motors, and such a development would at once upset the calculation given in the paper. The business of the electricity supply undertaking is to encourage the consumption of the maximum number of units, and this could be achieved more easily by reducing to a minimum the cost of the motors and of their maintenance.

Mr. Allcock showed pictures of what is really a farm machine for digging ditches, adapted to the laying of cables. Another farm machine used for cables is the mole drainer, which, when the soil is free of stones, is drawn through the ground; there is only a quickly-closing $\frac{3}{4}$-in. or 1-in. slot left in the ground above, while the mole down below provides the necessary space for the cable and also draws it into place.

Mr. G. W. Molle (*communicated*): It is interesting to note that, whereas there are about 380 electricity undertakings in this country using overhead lines, there are probably at least 1 000 different ideas as to the correct methods of designing, erecting, and maintaining such lines. Freak overhead systems are a curse, both to the manufacturer and to the purchaser of materials; they introduce quite unnecessary difficulties. Standardization of design has, however, been very greatly advanced during the past 2 years.

With regard to Mr. Dean's paper, Tables 1 to 6, 7L, and 7M, are of great practical use. I have never found much use for the figures given in Tables 7A to 7K, however, for the reasons the author gives on pages 756 and 757. I have found the differences in the pole-top arrangements and conductor-spacings used by different undertakings to be a great nuisance in practice, usually necessitating the re-calculation of loads on poles, which are given in tables as applicable at a certain height from the top. Sometimes this distance is 1 ft., sometimes 18 in., and sometimes 2 ft. It would be a great relief if a standardized pole-top arrangement were to be arrived at nationally, and if all safe loads on poles were always referred to the top of the pole.

The Commissioners' Regulations specify that poles shall not move in the ground. To comply with this, the foundation must be at least as strong as the pole. It must never be forgotten, however, that in designing lines we are dealing with an entirely fictitious set of weather conditions. The "ice-loading" specified has nothing to do with real ice, nor was it ever intended to have. This fact is not appreciated in some overseas countries, where designers still use a wind load only. My own researches into our climatic records have shown me that our worst conditions, experienced three times since 1880, have been a 75-m.p.h. gale coupled with ice formations which, irrespective of the size of the conductor, build up until they present a surface 2–3 in. wide to the wind pressure. In certain mountainous districts where overhead lines exist, snow blizzards have been experienced in which no anemometer was of any use, but the wind gusts are believed to have exceeded 150 m.p.h. All lines should stand a 75-m.p.h. blizzard, and it is of interest to note that lines on concrete poles have successfully withstood, in this country, very severe conditions under which wood poles have failed.

Experience alone can determine whether the various graphs given by the author will prove to be time-saving devices. I am inclined to agree with Mr. Fennell that the use of this paper should be confined to those who are already practised in the art of overhead-line calculations in this country. I have recently returned from an overseas country where knowledge of the principles of overhead-line design is not quite up to date, and I shudder to think of the consequences of the use of this paper by anyone who does not know how to modify the contents to suit local requirements.

Turning to the paper by Mr. Ross, my experience indicates that there is no advantage applicable to wood poles which is not also enjoyed by concrete poles of the right type. I recently started to compile a list of the advantages of concrete poles; though uncompleted, it already includes 87 items. I agree strongly that single-circuit lines on single poles should be used by rural undertakings. Even so, I have known cases where the fads of landowners, coupled with the requirements of the Post Office and railway authorities, have resulted in the final erected cost of 2 miles of 11-kV single-circuit line being no less than 3 times the estimated cost.

As regards galvanized-steel conductors, I carried out an experiment lasting over 3 years, with a sample of such conductor, to determine its resistance to corrosion under very severe and accelerated conditions. After being immersed at frequent intervals in salt water, in contact with other metals, for 3 years, it showed no signs of corrosion. The strands were tarred, between strands, but not externally.

It has always astonished me that so many figures for overhead-line costs have been published, with no mention of any details. The term "cost per mile" has never conveyed much to my mind, beyond a rough guide to the correctness of one's estimates. The cost of a completed line is the only figure of any significance, and even then, one needs to know the particular circumstances. I should like here to draw attention to the very misleading practice of some engineers, of comparing pole costs on a pole-for-pole basis. Only recently I found, when comparing the costs of a proposed concrete-pole line with the figure for wood poles, that, although the concrete poles were more expensive, the cost of the whole line, with concrete poles, was considerably less, owing to increased spans, fewer stays, fewer wayleaves, and general economy in erection costs.

It is difficult to generalize on the subject of bird trouble. There are parts of this country where trouble is experienced from birds with wing spans of 4 ft. 6 in. to 6 ft.

As regards insulators, the only reliable type is one which the maker will unreservedly guarantee to replace if it fails in service. I remember being told by one maker that he would undertake to make an insulator of a type which would comply in all particulars with the British Standard Specification, and yet it would certainly fail in service; but that he had a standard type, which did not comply with the Specification at all, which he could yet guarantee to give many years' reliable service. It is safest to be guided by the makers' experience, which is wide.

Although earth plates may be satisfactory on a high-tension line, an earthed conductor should always, if possible, be erected on a low-tension line. Usually, of course, the earthed conductor will be the neutral.

With regard to 60-ton steel wire, what is the author's experience regarding vibration, the difficulty of cutting, and the most suitable type of end-clamp?

I had some experience of rural transmission by 11-kV underground cable several years ago. A 0·06-sq. in. 3-core, double steel-taped armoured cable was laid for some 17 miles, in grass verge. The actual job was easy, rapid, and cheap. The difficulties lay in tapping-off *en route*, and subsequent mechanical damage. With regard to tapping-off, above-ground disconnecting kiosks were tried, designed to be accessible for future extensions. These were troublesome, as it was impossible to keep them dry, or to prevent the ingress of dust and insects. On the other hand, it is essential on underground rural cable to provide some such means of tapping-off without excavation, and without interruption of supply. After the cable had been laid for about a year, a navvy, working on a drainage scheme, put a crowbar right through a 2-in. marking-board and through the double steel-tape armouring of the cable below it, the crowbar passing right through the cable. Such occurrences should be guarded against, but this increases the capital cost. In the above case, the cable was laid at a depth of from 1 ft. 6 in. to 2 ft. 6 in., which should have been ample in a grass verge, with a marking-board and steel-tape armouring. Evidently a much greater depth is necessary, again increasing the cost.

With regard to switchgear and fusegear, a year or two ago I prepared a schedule of points to be considered when weighing the merits of any design. This ran to 23 foolscap pages of type, without any comments on the various points; the mere first cost of a switch is not necessarily the last cost. It is interesting to have the author's views on the installation of oil-break switchgear. Only a few years ago it was impossible to persuade bulk-supply vendors that oil-break switchgear was a needless extravagance on a rural undertaking, and much money must have been wasted on this item in various places. Since the advent of the grid, however, it has become advisable to reconsider this matter, because of the vast power behind a fault. My experience leads me to favour the indoor substation, wherever economically justifiable. The main essential is warmth and dryness, and a mere switchgear kiosk which does not contain transformers, or, alternatively, has no provision for heating, is useless. Has the author had any experience of the bonderizing or parkerizing processes for rust-prevention?

With regard to transformers, I would go even farther than the author, and say that, as far as ground-type transformers are concerned, it is hardly worth while installing one of less than 25 kVA. Good regulation is the most important asset.

It is interesting to see single-phase supply advocated in the paper. Within the last 10 years, at least one large scheme designed for single-phase supply throughout has been rejected by the powers-that-be, though, more recently, single-phase practice has become more popular. Fashions in electricity supply seem to recur in cycles.

The authors will find some remarks on earth resistances in my paper on "Corrosion, with Special Reference to Overhead Lines," read before the Overhead Lines Association in 1930.* My own experience of earth plates is that one can never rely on them; their resistance varies from day to day. I believe burying a few turns of copper wire gives a better result. One of the biggest power companies has found it necessary, I am told, to surround each transformer neutral earth-plate with as much as 15 cwt. of coke. Another has found that a mass of concrete forms an excellent earth (a reassuring fact in connection with concrete poles). There is much interesting information on the subject of rural earths in Dr. Ekstrom's book "Rural Electrification."

Has the author experienced the puncturing of service cables and the burning-out of meters, by lightning? Suitable arrestors for house-service protection are, of course, available.

Mr. G. W. Preston (*communicated*): The two authors agree as to the type of conductor to be used for low-tension lines, but their opinions differ in the case of conductors for e.h.t. lines. Mr. Dean advocates the use of cadmium-copper conductors, while Mr. Ross prefers to use steel-cored aluminium. I am entirely in agreement with Mr. Dean and am of the opinion that with copper round about its present price Mr. Ross would have difficulty in supporting his choice of conductor, either on technical or on economic grounds.

Mr. Dean sets out the relative merits of various conductors in Table 8A of his paper. He shows clearly that a cadmium-copper line is no more costly than one employing S.C.A. conductors, and that the former has the added advantage of about two poles less per mile, resulting not only in a saving in wayleave and compensation costs but also in a reduction in the number of insulators and points at which trouble may develop.

He points out that on medium-span lines the use of steel-cored copper conductors results in the cheapest possible line for conductors other than those of the very smallest sizes. Nevertheless, Mr. Dean prefers to use the slightly more expensive cadmium-copper conductors and, if he is desirous of using the best possible material, I think that he is perfectly right in choosing conductors of this type, if only on the score that a homogeneous conductor must always be preferable to one of the composite type incorporating a ferrous material.

It cannot be denied, however, that steel-cored copper conductors offer a very attractive proposition for rural lines and I do not think that Mr. Dean need have any undue fears as to their reliability, since there are conductors on the market at the present time which, as far as can be seen, promise to give absolutely reliable and first-class service over long periods.

At the present time there are many hundreds of miles of conductors of this type in service on rural lines in this country. To mention only one example, Mr. Sumner stated in his recent paper* that practically the whole of the 11-kV lines on the system with which he is connected had steel-cored copper conductors, there being more than 200 miles of such 3-phase lines.

THE AUTHORS' REPLIES TO THE DISCUSSION.

Mr. R. Dean (*in reply*): It was only to be expected that most of the discussion would centre around the graphs and tables relating to values of earth foundations. At the time the paper was being prepared I fully appreciated that these were a variable quantity and deliberately included them in the hope that discussion and constructive criticism would arise, so as to bring forward any further information that might be available.

Mr. Fennell suggests that, apart from the sag tables, considerable caution should be exercised in allowing the remaining data to be used, and that the information relating to pole foundations is very dubious. Some of the graphs are fairly complicated, but in order to overcome this difficulty, and to ensure their easy application, worked examples were given for every graph. It was felt that this should be sufficient guidance, particularly as engineers already familiar with overhead-line practice would not be altogether groping in the dark. I cannot, however, agree that any undue caution need be exercised in making use of the data.

It is acknowledged that much of the adverse criticism of overhead distribution lines which has arisen in the past amongst the general public, and even within our own industry, has been due to the lack of information in a form easy of application, and to the many examples of really atrocious forms of construction, which lacked balance, symmetry, or even elementary engineering principles. During recent years tremendous improvements both in engineering design and in general appearance have been apparent, but the published data are still very meagre. Although the data contained in the paper are not intended for indiscriminate use by engineers not versed in overhead-line practice, even so they may enable an improvement to be made on the practice of leaving the actual design to the discretion of a lineman.

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* *Proceedings of the Overhead Lines Association*, 21st May, 1930, p. 272.

* *Journal I.E.E.*, 1935, vol. 77, p. 310.

The information is put forward with every confidence; it is based on many years' technical and practical experience of overhead-line design and construction, and every reasonable care has been taken to ensure its being reliable. It cannot, however, be claimed that all the data have been submitted to the Electricity Commissioners' staff for approval, and I hope that any contentious matter will now be fully investigated and discussed with a view to some measure of agreement being reached. In all, the paper contains some 20 tables and 25 graphs, and of these only one table (No. 5) and six graphs (Figs. 4A to 4F), which relate to earth foundations, may be considered to be in any way contentious.

It would have been quite an easy matter to have evaded the subject of pole foundations by stating that pole foundations are too variable to be dealt with by means of a graph, as in the case of Mr. Fennell; or that they are designed by rule-of-thumb methods and past experience, as mentioned by Mr. Boyse; but unfortunately such statements are not helpful, nor do they lead any nearer to a solution.

I agree that the only satisfactory method of determining the values of ground reaction for single or Rutter-type wood-pole foundations is by tests on site, such as driving a standard size of pile into the ground in question and ascertaining the load it will withstand for a certain deflection. This has already been done by various authorities in different parts of the country, and results have been obtained for normal ground which agree very closely with those obtainable from the graphs. For the type of construction under consideration, namely single wood-pole lines for rural distribution, probably 80 per cent of the foundations occur in what may be described as normal ground, and it is felt that the method of analysis which has been put forward will provide far more accurate results than the lack of system so often used in the past, which in many cases has amounted to very little more than a broad guess.

Where bad ground such as rock, bog, wet clay, etc., occurs it is obvious—even to the most inexperienced—that conditions are abnormal, and, as such, must receive special consideration and investigation. For normal ground the figure of 1 000 lb. per sq. ft. per ft. of depth may be taken as a safe average value for depths up to 7 ft. or 8 ft. for wood-pole lines, using single or Rutter-type poles. It is my experience that the depths given by the graphs on this basis slightly exceed those in general use for wood-pole line construction. Should this value, after preliminary investigation in any particular locality, prove to be too high, however, then the lower value of 800 lb. per sq. ft. per ft. (also covered by the graphs) can be substituted.

It will be appreciated that the foundations of wood poles are not usually subject to sustained loadings, as is often the case with fabricated-steel poles. Where sustained loads occur on wood-pole lines they are almost invariably dealt with by suitable stays or struts. An intermittent load on a pole does not subject a foundation to so severe a test as a sustained load; and further, in dealing with wood poles, a slight movement —up to even 2 ft. at the top under severe conditions— would usually not prove disastrous, although not strictly complying with the Commissioners' Regulations.

In the case of Figs. 4A, 4B, 4C, and 4D, allowance has been made for the added taper of wood poles below the ground line, due to the natural butt. The effect of this is to increase the area available and result in foundation values between 15 and 25 per cent higher than in the case of poles of uniform diameter below ground line, for the same depth of setting. The allowance made for this taper has been on the conservative basis of approximately 15 per cent and has resulted in the depths of setting shown in Fig. 4A being approximately 5 per cent less than would be the case for poles of uniform diameter below ground. In the case of Figs. 4B, 4C, 4D, and 4E, however, the effect upon the size of kicking-block required is much more marked.

It will be noted that curves A, B, and C in Figs. 4A to 4E inclusive are based on the "safe working load of pole at ground line," which is equivalent to a foundation value approximately 15 per cent less than that corresponding to the "total value of the pole foundation." This has the effect of compensating for taper below ground and is again on a somewhat conservative basis.

Should it be required to use Figs. 4B, 4C, 4D, and 4E, for ascertaining the size of single kicking-blocks required when using poles of uniform section below ground line, this can be done by adding approximately 15 per cent to the values given by curves A, B, or C. The effect on the size of kicking-blocks required in the case of ground having a safe resistance value of 1 000 lb. per sq. ft. per ft. of depth is shown in Table A.

Mr. Fennell states that it is customary to have not more than seven or eight different designs on any one supply undertaking and that these should be carefully worked out. This, it will be realized has, in the past, been a laborious task; so much so in fact that, once carried out, the results were likely to remain in force for a considerable time, irrespective of changes in the price of metals for conductors, supports, etc. I pointed out in the Conclusion to the paper that, in view of the frequent wide variations in the price of conductor metals, it was essential that it should be possible to make ready comparisons of the relative economy of different types of construction, span lengths, or conductor materials. This involves some easy method of arriving at the required results, and it is hoped that the data contained in the paper may prove helpful in this direction, and thus facilitate full advantage being taken of any cheaper types of construction which may be available as a result of changing markets.

In connection with the raising of the fulcrum point, I think Mr. Fennell is here under some misapprehension. My reference to this matter was in connection with the use of single kicking-blocks. I agree that the relative densities of the soil determine the position of the fulcrum point for a pole foundation without the kicking-blocks, but where the latter are used they have a very marked effect on the position of the fulcrum. It is obvious that, if a kicking-block of infinite length were attached to a single pole just below ground-level, the fulcrum point would actually be raised to practically the centre of the kicking-block. Thus by using blocks of varying cross-sectional area it is practicable to vary the position of the fulcrum point appreciably and in this way increase the total value of the pole foundation.

Assuming fairly uniform increase in ground resistance with depth, it is possible by means of Figs. 4B, 4C, 4D, and 4E, to determine readily, with reasonable accuracy, the size of kicking-block required for poles of various diameters when buried at a definite depth.

I wish to thank Mr. Ridd for drawing my attention to, and kindly supplying me with a copy of, a recent paper by Mr. W. H. Brent on " The Telegraph Pole."[*]

With regard to the type of hole excavated for receiving poles, the stepped hole is generally used on power lines, particularly on high-tension lines across country. On the smaller holes for l.t. distribution-poles the bar-and-spoon and auger are used, but only to a limited extent, probably owing to the fact that their use necessitates lifting a pole bodily and dropping it into the small circular hole. Where a crane lorry is available this operation presents no difficulty, especially for routes alongside roadways, and in such cases I agree that the method will result in considerable economies in addition to providing a more stable foundation, particularly at the outset. The use of a crane lorry across fields is not always practicable, nor, on account of damage to crops, is it welcomed by the landowner.

TABLE A.

Comparison of Sizes of Single Kicking-Blocks Required for use with Single Poles, based on Ground having a Safe Bearing Value of 1 000 lb. per sq. ft. per ft. of depth. (Values on left make allowance for taper of pole below ground, values on right are for use with poles of uniform diameter below ground.)

Pole diameter (in.)	Area of kicking block (sq. ft.), excluding area covered by pole							
	With allowance for taper				With no taper			
	(5·5)	(6)	(6·5)	(7)	(5·5)	(6)	(6·5)	(7)
10	1·35	0·15	—	—	2·3	0·75	—	—
10·5	2·1	0·55	—	—	3·3	1·4	—	—
11	3·1	1·2	—	—	4·7	2·17	0·65	—
11·5	4·3	1·95	—	—	6·3	3·15	1·2	—
12	5·7	2·7	0·85	—	8·2	4·3	2	0·35
12·5	7·3	3·75	1·5	—	10·7	5·8	2·85	1·0
13	—	5	2·35	0·45	—	7·5	3·9	1·65
13·5	—	6·4	3·3	1·15	—	9·4	5·2	2·5
14	—	8	4·45	1·9	—	10·7	6·7	3·5
15	—	—	7·2	3·7	—	—	10·7	6
16	—	—	—	6	—	—	—	10

Numbers in brackets give depth of setting, in ft.

In reply to Mr. Ridd's query regarding joint construction for power-distribution and communication services, I have had no actual experience of this. Such a proposal should, however, be particularly suitable for very scattered areas and for long branch lines to isolated premises. In the case of routes involving high-tension lines the proposal would necessitate the use of conductors for the communication circuits of very high tensile strength such as bronze or copperweld, and relatively short-span construction for the power lines. Further, protective arrangements would have to be provided as a safeguard against possible contact between the two systems, and special precautions would be necessary to prevent inductive interference. There are already a number of routes in existence where joint construction has been adopted, but the communication circuits have been for the private use of the owners of the power line.

I have already referred to Mr. Boyse's remarks regarding the method of designing pole foundations by rule-of-thumb and past experience. As to the earth-resistance values in lb. per sq. ft. per ft. of depth used in the graphs, these, as stated on page 772, were based on normal types of ground, and 1 000 lb. per sq. ft. per ft. of depth was put forward as a safe average value for such ground (firm earth reasonably free from sand or clay). In loose sandy soil the safe value may vary from 400 to 800 lb. per sq. ft. per ft. of depth, and a test on site is the only effective guide. Where clay is encountered, however, the conditions are totally different, and the graphs do not apply, as the earth pressure is proportional not to the depth below the surface but simply to the amount of movement. Clay may be considered to be a mobile or semi-viscous body, and the results obtained will largely depend on its moisture content and the duration of the applied load. As a result, movement in a clay foundation does not occur immediately the load is applied, and thus, although clay may be capable of providing fairly good results for foundations subject to intermittent loads, it is very treacherous for dealing with sustained loads.

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[*] Institution of Post Office Electrical Engineers, Professional Paper No. 154.

With regard to the criterion of failure, this largely depends on the type of pole foundation under consideration. In the case of "A" poles, "H" poles, or wide-base towers, failure generally occurs owing to uplift of the tension member, and it will be appreciated that once this commences there is nothing to prevent complete failure of the foundation. As already stated in my reply to Mr. Fennell, poles of these types are often used without stays, for dealing with sustained loads, as at angle or terminal positions, whereas single pole foundations usually deal with intermittent loads only. Further, with single or Rutter-type poles, slight movement can take place without serious risk of complete failure of the foundation, as mentioned by Mr. Broadhead. Although the Commissioners' Regulations make no differentiation, I suggest that, in view of these practical differences in the nature of failure of the two types of foundations, the factor of safety against movement need not be so high in the case of single or Rutter-type poles as in the case of multiple-member poles or stay blocks. For single or Rutter-type poles, a slight movement—up to, say, 6 in. at the top of a pole 30 ft. above ground level (excluding any deflection in the pole itself)—should be allowable, and would, in my opinion, still provide a reasonable factor of safety against complete failure. It should further be remembered that any slight movement of the pole will often relieve the applied stresses.

An examination of Table 5 will reveal that the values of ground resistance per square foot in the case of stay blocks are on a very conservative basis, so as to ensure no movement whatever of the blocks. The factor of safety of 2·5 in connection with Figs. 4A to 4F, referred to on page 773, is against complete failure of the foundations.

I agree with Mr. Boyse that the application of the safe working loads shown for poles of different diameter in Fig. 4A, when using the depths of setting indicated by curve B (based on 1 000 lb. per sq. ft. per ft. of depth), would probably result in a slight movement of the poles in average ground, and thus not strictly comply with the Commissioners' Regulations. I do not think, however, that the movement would be sufficient to cause this type of foundation to be unsafe, for reasons already explained.

It is doubtful whether even the depths of setting indicated by curve C would prevent any movement whatever for poles when buried in normal ground, although these depths would probably result in the breaking of the pole before complete failure of the foundation, i.e. complete uprooting of the pole.

My replies to Mr. Fennell and Mr. Boyse should, I think, cover most of the points raised by Mr. Broadhead. With regard, however, to the depths of setting in normal ground, I prefer to use the formula $l^3 = 10M/(kd)$, where l = depth of setting (ft.), M = applied moment (lb.-ft.), d = pole diameter (ft.) at ground line, k = safe bearing value of earth (lb. per sq. ft. per ft. of depth). This formula is based on a rupture intensity for the soil directly proportional to depth, and makes no allowance for taper below ground, although this was done in Fig. 4A. The formula gives depths allowing considerable movement of the pole before breakage, which, in the case of single or Rutter-type wood poles, is desirable.

Mr. Borlase Matthews has slightly misconstrued my remarks in connection with fabricated-steel or concrete pole lines. On page 750 of the paper I stated that both reinforced-concrete and fabricated-steel poles have been found to be from 10 to 15 per cent dearer than wood poles. As the cost of poles, however, usually represents some 30–40 per cent of the total cost of the line only, the use of such poles would result in the total cost per mile being only about 5 per cent higher than in the case of wood poles, were it not for the additional transport and erection costs. It will be appreciated that span lengths between 500 ft. and 600 ft. can only be used on rural lines in flat country, and single wood poles are capable of dealing economically with the loads involved for the relatively small conductors generally used. Fabricated-steel and ferro-concrete poles are recommended for extra-high voltages where the cost of long strings of insulators necessitates long-span construction on economical grounds and thus higher and stronger supports are called for. They are also necessary in many foreign countries where wood poles would be unsuitable owing to climatic conditions and attacks by insects. Fabricated-steel poles are relatively costly to maintain, as, if they are to have a reasonable life, they must be painted regularly. Ferro-concrete poles are much to be preferred for rural distribution, but until the total cost of these, including transport and erection, can be lowered, I must repeat my recommendation to use wood poles as the most economical proposition at the present time.

With regard to the drilling of the wood poles for insulator bolts, as shown in Fig. 8, (*a*) and (*b*), this is quite a different proposition from drilling holes in the poles below ground line. Near the top the pole is of ample strength for the loads involved, and the only precaution which need be taken is to fit washers having a large bearing surface at the back end of the through bolts at angle and terminal positions, so as to ensure that the maximum compression stresses on the timber do not exceed 450–500 lb. per sq. in.

I regret that, owing to the large number of variables involved in most of the graphs, it is impossible for me to present the information in any clearer form, such as an abacus or nomogram, as suggested by Mr. Borlase Matthews.

I agree with Mr. Molle that standardization is most desirable, but his reference to the sag tables is erroneous. Of these, Tables 7A to 7H are based on the regulations for high-voltage lines and are in everyday use; my reference on pages 756 and 757 was to Tables 7J and 7K only, which are based on the regulations for low-voltage lines. Although these are the figures usually published for low-voltage lines, they are of very little practical value owing to the excessive stresses which are involved. Tables 7L and 7M were therefore prepared in their stead, and cover the three sizes of conductors in general use for low-voltage distribution lines.

In reply to Mr. Preston, I find on checking the total costs in Table 8A that I had inadvertently omitted the cost of capitalized wayleaves as mentioned on page 789 of the paper. This mistake has now been rectified and the effect is to strengthen still further my recommendation of cadmium copper for medium-span construction.

With regard to copper-cored steel and steel-cored copper conductors, since the reading of the paper my fears as to electrochemical action have proved to be well founded; I have recently been informed, on reliable authority, that trouble due to this cause is being experienced fairly extensively on a number of such lines. I regret that this trouble should have occurred, as these conductors would otherwise have proved particularly attractive for high-voltage rural distribution lines, where relatively small amounts of power were involved.

Mr. D. Ross (*in reply*): Replying to Mr. Fennell's first question, wayleave rentals commuted to 18 years' purchase were agreed with the landowners in the county where I am at present engaged, and this is considered to be a fair basis for agricultural land.

Mr. Markham rightly questions the costs given for overhead lines. I am not at all surprised, as figures have frequently been given in the past which certainly do not include all incidental costs. This is the very point I stressed in my paper. The costs given cover all possible contingencies, for work carried out throughout the year in all types of weather and under all conditions, and are based on standard rates of pay obtaining throughout the country. These costs, however, apply only to a relatively large construction programme. For short lines there is no doubt that they would be exceeded. I disagree with Mr. Markham's views that there is no need for any metal but aluminium if stirrups are used. This type of binder is disliked as it is much too rigid, particularly where adjacent spans are unequal in length, and has resulted in breakage of insulators and binders. His objections to galvanized soft-iron binding wire are not understood as, provided an aluminium-tape chafer is wrapped round the conductor before the binding wire is applied, there is no possibility of bimetallic action between the binder and the conductor. Mr. Markham appears to have misread my statement regarding binders for galvanized-steel conductors. I cannot agree with the suggestion that copper stirrup binders should be used with galvanized-steel conductors, on account of bimetallic action. Obviously it is preferable to use the same material for binding wire as the conductor if this is of suitable strength.

Referring to the questions put by Messrs. Molle and Preston, concrete poles have many advantages and can be economically used in certain circumstances. I cannot agree, however, that they can be employed so universally as wood poles, as they are much more difficult to transport.

Bird trouble has now been overcome with a spacing of 4 ft. 6 in. and a clearance to earthed metalwork of 1 ft. 6 in., although it is possible in some isolated cases that a particularly large bird may still cause an interruption. Fortunately, large birds capable of short-circuiting the conductors are rare.

I agree with Mr. Molle that, although an insulator may conform to the British Standard Specification, it does not signify that the insulator will be satisfactory in service. So far as 11-kV insulators are concerned, however, certain designs have now been in use for nearly 20 years, and operation experience has proved them to be most reliable.

There is no indication that trouble from vibration will be experienced on 60-ton-breaking-stress steel conductor. It is, however, too early to give definite information on this subject as this type of conductor has been in use for only a few years. The effects of vibration, moreover, would be less harmful than in the case of S.C.A. or copper, as the fatigue strength of this material is higher. There is no difficulty in cutting or handling this material in the field.

Whilst I put forward S.C.A. conductor as being the most suitable for rural distribution I also admit that there is no appreciable difference in the relative costs of construction between the various types of lines employing different conductors at the present price of metals. It must be remembered, however, that copper varies in price much more than other conductor materials, and it is only a few years since the price of copper stood at three times its present level.

Sufficient experience has now been obtained with aluminium conductor to prove its satisfactory behaviour in service, but the same cannot be said for cadmium copper, steel-cored copper, and copper-cored steel conductors, and until sufficient experience is gained I shall hold to my present views.

In reply to Messrs. Fennell and Allcock, the costs put forward for underground cables are only for rural cables and are comparative figures, and it must be borne in mind that the route of an underground cable would generally be longer than that of an overhead line. Further, no allowance has been made in these figures for the breaking-up of roadways or other paved surfaces, or for extra depths to give clearance to pipes and other obstructions, all of which add considerably to the cost of underground work in urban districts. Moreover, in connection with underground mains it must be remembered that the cost of tapping and installing of sub-stations is considerably greater than for overhead lines. For instance, an 11-kV line can be tapped for a few shillings and protected by means of fuses at a cost of approximately £11, whereas the tapping of an underground cable would cost at least £10 and with an oil-switch fuse the cost would be £60–£70.

It is interesting to note that efforts have been made to produce a special rural cable having the thickness of dielectric much less than that permitted for urban distribution, as I am of the firm opinion that there are many instances where the installation of underground mains can be fully justified.

Replying to Messrs. Laverick, Pooley, and Markham, I agree that robust switchgear only should be used for outdoor work, and whilst most engineers are prepared to purchase a more expensive article it was mentioned that sectionalizing switches were available which cost £15 11s. erected. This was really to indicate that it is practicable to sectionalize overhead lines at numerous points at a comparatively low cost. I should like to point out, however, that it is not always the most expensive switch which is the most satisfactory. Frequently a simple arrangement with few moving parts produced at a low cost gives much more satisfaction.

With regard to the criticism regarding the plug-in type of fuse, I think Mr. Laverick is unduly pessimistic as these have been in use for over 3 years and no trouble has been experienced from the suggested causes.

Referring to the suggestion of leakage across the porcelain of the unit having only one supporting insulator, the leakage path is approximately 19 in. and is completely protected from the weather. It is therefore highly improbable that any leakage will take place. I have tested this type of insulator for leakage after it has been in service for over 2 years at 3 times the working voltage, and have been unable to get a deflection on a millivoltmeter.

With regard to the objection that it is impossible to detect a blown fuse of this type from the ground-level, I consider this to be an unimportant point as it is more satisfactory to inspect both fuses should a failure occur, and as it only takes 1 minute to withdraw and replace a fuse there can be no question of financial loss.

Replying to Mr. Pooley's question regarding discrimination obtained between various sizes of h.t. fuses, I confirm that, with a cartridge fuse of modern design and correctly graded, operation in the appropriate sequence will be obtained.

Although no reference is made in the paper to a vertical tandem switch, I have used this for certain positions and have found it most adaptable.

The type of open-wire fuse mentioned may be satisfactory, but generally this class of fuse has proved most unreliable for the protection of 11-kV equipment and does not provide discrimination. From an operation engineer's point of view it is considered of little importance whether an indication is given that the fuse has blown, as obviously the first intimation that this has occurred is a complaint received from the consumer that the supply is off.

I have not considered the use of live-line connectors instead of isolators as, although I have revolutionary ideas on this matter, there is a considerable element of danger in this method of disconnecting apparatus, particularly in the field.

I desire to emphasize that a clearance of not less than 18 in. is provided on all fusegear connections, and where this cannot be obtained porcelain fish-spine insulators or pernax tubes are used. Where jumpers are unduly long, pilot insulator supports are used.

Regarding fuse rating for spur lines with 8 transformers connected, generally a 4- or 6-ampere fuse is used which will carry the charging current of the line and the transformers and at the same time give the necessary short-circuit protection for the smallest transformer used.

Referring to the remarks of Messrs. Fennell and Borlase Matthews, I am aware that the Overhead Lines Association produced a specification for transformers, although when my paper was originally prepared this specification was not available. I am not, however, in entire agreement with the specification as I consider that a 15-kVA 3-phase transformer should be included and the 100-kVA single-phase transformer omitted, and the secondary no-load voltage should be 240 instead of 230 volts with $\pm 2\frac{1}{2}$ per cent and 5 per cent tappings. Moreover, the formula does not take into consideration the regulation of the transformer except so far as this is specified to be of low value. If Mr. Fennell cares to work out the capitalized loss in accordance with the Overhead Lines Association's Specification he will see that my figures are in very close agreement.

In reply to Mr. Butler's question, I am of the opinion that a single earth wire erected above or below the power conductors does not provide satisfactory protection. My experience of lines equipped with and without aerial earth-wires does not prove that the aerial earth-wire is effective. I can recall a particular 11-kV line which crossed the Pennines in South Yorkshire and which was subject to severe interruptions during thunderstorms, and as an experiment an earth wire was erected above the power conductors but no improvement was observed.

I agree that the protection of several transformers with only one set of h.t. fuses is a tribute to the reliability of modern transformers, and actual experience has definitely proved this to be the case, as on the system with which I am at the moment connected, over 500 pole-mounting transformers are in use and not one has been damaged by lightning, although a considerable number of protecting fuses have been found blown.

Mr. Butler refers to three or four probable reasons why fuses are blown in a lightning storm, and it is very difficult to say which of these is the cause. I am disturbed at the suggestion of minute punctures taking place in the insulation and can hardly credit that transformers would continue to function properly for any length of time under such circumstances. The second reason put forward is a possible solution but the third reason is more probable, i.e. charging current due to the capacitance of the transformer plus the overhead line, particularly with 6 or 8 transformers connected to the one spur line, which, with the high frequency of lightning, would probably result in a charging current of sufficient magnitude to blow fuses. The suggestion that a flashover always takes place on the insulators can be ruled out, as careful examinations have disclosed that this is not necessarily the case. Generally speaking, the power arc which follows a flashover causes considerable damage to the insulator and is quite visible, but I have considerable experience of fuses being blown and no visible sign of a flashover or damage being caused. It is therefore suggested that the cause of fuses being blown is probably either the second or the third reason put forward, or a combination of both. This matter is of great importance and it is hoped that further light will be thrown upon it in future discussions.

Not only are 50-kVA transformers erected on single poles but transformers as large as 150 kVA have been erected on single wood poles suitably reinforced back and front with 10 in. × 5 in. channel iron; a very neat and inexpensive arrangement is obtained.

Dealing with the questions put by Messrs. Fennell and Markham regarding the cost of insulated conductors erected on buildings, the figures given are for insulated conductors which conform to the following specification:—

"The conductor shall be insulated with compound dielectric of 600-megohm class, which shall be concentric with, and shall have no deleterious effect upon, the conductor. It shall be flexible and reasonably elastic, weatherproof, and unaffected by sunlight, long exposure to moisture, or by temperatures not exceeding 150° F.

The conductors shall not decentralize under normal use.

"The dielectric shall be covered with a closely woven cotton tape, without selvedge edge, of suitable thickness, heavily coated with a suitable water- and oil-resisting material. The tape shall completely cover the dielectric and shall be easily removed therefrom.

"The taped conductors shall be finished with a close braiding of cotton of suitable radial thickness, and the braiding shall be thoroughly impregnated with a red lead compound, of which not less than 70 per cent shall be genuine red oxide of lead. The cable shall be of smooth and even finish, and there shall be no tendency for the compounding to come off in the process of handling."

These conductors are attached to the wall by means of non-ferrous metal clips fixed by rawlplugs and galvanized screws and spaced approximately 12 in. apart.

My reason for using solid 0·06-sq. in. conductor on l.t. lines, is on the ground of economy, as this type of conductor is cheaper than the stranded conductor and is just as easy to handle and does not kink. Solid conductor above this size should certainly not be used. It is agreed that split neutrals for l.t. crossings over the G.P.O. lines should be avoided wherever possible. I only permit their use for economic reasons, and where only one or two wires of relatively small section are to be guarded then it is preferable and cheaper to use insulated conductor.

It is not necessary to seal the ends of the lead-in cables as the insulation is compound rubber and fills up the interstices between the strands.

I have had experience of the use of the "Wonpeace" insulator and have found it useful under certain circumstances.

Mr. Borlase Matthews raises the question of motor sizes. It was not assumed that a farmer would only require a 1-h.p. and a 5-h.p. motor. These two sizes were merely selected to show comparative costs, as these sizes certainly constitute at least 80 per cent of the motors used on farm work, and rarely is a motor greater than 10 h.p. required. In the light of experience already obtained, the amount of power required by farmers has been grossly exaggerated. Therefore there is no reason to believe that many motors of larger horse-power than that given will be used.

I agree with Mr. Borlase Matthews's views that the business of the electricity supply undertaking is to encourage the use of electricity, but this can only be achieved on economical lines and surely it is much better for the farmer to be called upon to pay, say, £15 more for his motors than for the supply authority to be faced with an additional capital expenditure of £100, as obviously this additional cost must be passed on to the consumer, and would only have a tendency to restrict the development, not to encourage it.

I do not agree with Mr. Gilbert's suggestion that supplementary contacts should be fitted so that the trip-coil circuit is broken when the switch opens. In the event of a fault occurring in the transformer the h.t. fuses or switchgear will operate and the conditions here are no different from those of the standard arrangement, so far as protection against this possible fault is concerned. It will be appreciated that the transformer and its contingent fuse and/or switchgear are separately earthed, so that in the event of a failure of the insulation the earth trip-circuit is not called upon to deal with the fault current. Regarding the suggestion that the action of this switch should be slightly delayed so that momentary transient faults do not necessarily trip the switch, this is provided for in two ways:—

(1) The earth leakage has an adjustable trip.
(2) The earth-leakage circuit is in parallel with the main neutral earth, and consequently only a portion of the earth-leakage current passes via the earth trip-coil, whereas the earth-leakage circuit breakers on consumers' premises are directly connected to the earth electrode. Discrimination is therefore provided.

Replying to Mr. Markham's queries regarding the higher resistance obtained for Test No. 8 as compared with Test No. 6, I can only put this down to the assumption that, although the electrodes were buried in the same type of ground, it is possible that in Test No. 6 the top surface soil had become mixed with other soil, which would probably result in the resistance being lowered. It is extremely difficult in these tests to keep the excavated soil completely isolated from other soil and foreign substances.

With regard to the lower resistance in Test No. 4 as compared with Test No. 2, I think this was explained in the paper and is due principally to the top surface of the soil containing foreign matter such as decayed vegetation, salts, or fertilizing agents, which result in a lower resistance being obtained.

The time intervening between treatments in Table No. 9 varies from 1 to 3 days, but it was actually found from the tests taken that this variation did not materially affect the reduction in resistances. It was only after additional treatments that the resistance was lowered, and finally a resistance was reached when further treatments did not affect the resistance.

That a reading of 3 ohms was obtained on the cable armour is well known, and only goes to prove that it is much easier to obtain a satisfactory earth by laying a length of cable or conductor near the surface where the resistance of the soil is relatively low, than by burying earth plates at a great depth.

Replying to the question put by Messrs. Ridd and Molle regarding lightning protection for the consumer, so far as I am aware it is not the practice of supply authorities to install apparatus for this purpose. Perhaps the reason why protectors are not essential on l.t. distribution as compared with Post Office circuits is that l.t. overhead distributors are relatively short compared with Post Office circuits, the induced lightning charges therefore being correspondingly less. Unless a direct stroke occurs, trouble from lightning is not likely to be serious. My experience actually bears this out in that comparatively little damage is caused to the consumers' installations, a few isolated cases being known of meters being damaged and main fuses blown.

The cost of house-service arrestors for rural distribution cannot be justified, particularly as the possibility of damage is small.

ELECTRIFICATION OF RAILWAYS.*

By A. M. WRIGHT, M.Sc., Associate Member.

(*Paper first received 14th September, 1934, and in final form 22nd February, 1935.*)

SUMMARY.

Physical Characteristics of Steam, Oil-Electric, and Electric, Rail Tractors.

The principal competitors of the electric tractor are the steam locomotive and the oil-electric tractor.

The physical limitations and performance of these tractors are compared, and it is shown that the limited output and poor weight efficiency of the steam and oil-electric tractors offer serious handicaps in competition with electric traction.

Economic Aspects of Electrification.

(*a*) To take advantage of the superior performance of electric tractors entails large capital expenditures for track equipment and substations. An approximate equation is deduced showing that there is a permissible economic capital expenditure for electrification, in pence per ton-mile carried per annum.

(*b*) To determine whether a railway can be equipped for electric working at a cost not exceeding this economic maximum, a hypothetical example for handling varying tonnages of goods traffic is tabulated, the costs of equipping the track for electric working are given, and the annual operating costs are compared with those for steam haulage.

This demonstrates the economic feasibility of railway electrification where the traffic density is fairly high.

Appendix.

An appendix is added in which the physical and economic characteristics of the distribution circuits of an electric railway are discussed. It is shown that, from an economic standpoint, the single-phase system shows attractive possibilities.

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(1) INTRODUCTION.

The fundamental purpose of a railway is to produce transportation, that is, to add value to the products of industry by transporting them from the place where they are produced to the place where they are to be consumed. In the case of passenger transportation, a service is performed in conveying the passenger from the starting-point to his destination.

To serve the needs of a country, a certain number of units of transportation, usually measured in ton-miles or passenger-miles, must be produced every year by the transport system. This system, comprising the railways, the highways, and the waterways, must be capable of applying to the commodities of trade the intangible asset called " transportation " in whatever quantity may be demanded. It is not merely sufficient that the transport system be capable of producing a given number of ton-miles per annum; it is often essential that the units of transportation be produced very rapidly. The manner in which this requirement is met by railway lines is so evident as to require no comment. Having solved this physical fundamental, there remains the equally important matter of producing the transportation units as cheaply as possible. This part of the transport problem is partly an engineering and partly an economic one. The title of this paper indicates its restriction to a discussion of the solution of this problem by electric working of railways. In the sequel the author will attempt to show that the physical superiority of electric traction is so great as to warrant serious consideration, and from an economic standpoint the conditions will be discussed under which it is possible to take advantage of these superior qualities of the railway electric tractor.

In an electrification project it is necessary to provide a source of electric energy and to build a distribution system for supplying electric power to the trains. For this reason the application of electric traction to railway transport is a matter of economics as well as of engineering. The distribution system and other apparatus incident to electrification entail large expenditures of capital. The charges on this expenditure, when divided among the total number of traffic units produced by the electrified system, are in the final analysis the deciding factor for or against electric working of a railway. It is evident that if electrification is to be seriously considered, the physical superiority of the electric tractor must be very great. Before investigating the functional relation between traffic density and the economic value of electrification, then, the physical characteristics of the common types of rail tractors will be discussed.

The development of the heavy-oil engine in recent years has introduced a competitor to the electric tractor for certain types of railway service; the oil-electric drive offers some of the advantages of electric locomotives without the necessity for heavy expenditure for track equipment. It has sometimes been claimed that the oil-electric locomotive can duplicate the performance of an electric locomotive at a lower total cost. It can be stated definitely, however, that while the total annual cost of handling traffic with oil-electric tractors may be less than the total annual cost (including fixed charges) of electric traction where the traffic density is fairly light, the oil-engine equipment cannot hope to compete with the electric tractor in performance. To see how the limitations in the performance of these three types of traction arise, a brief analysis is given of the characteristics of steam, oil-electric, and electric, traction.

(2) PHYSICAL CHARACTERISTICS OF STEAM, OIL-ELECTRIC, AND ELECTRIC, RAIL TRACTORS.

(*a*) *Steam Tractors.*

The fundamental index to the output of a steam locomotive is its firebox grate area, since, other things being equal, the horse-power developed by the locomotive depends on the rate at which the fuel can be burned. The relation between the rate of burning of the fuel and the horse-power output is shown in the characteristic curve of Fig. 1 for a locomotive having a firebox grate area of 45 sq. ft. This curve applies to the medium and higher speed ranges of operation, where the horse-power remains fairly constant for any given rate of firing. The maximum output occurs when the rate of firing is about 150 lb. of coal per sq. ft. of grate area per hour. The maximum thermal efficiency, however, occurs when the locomotive is developing only about half of its maximum output. Fig. 1 applies to a simple-expansion superheated engine, burning bituminous coal of 14 000 B.Th.U. per lb. heat content. For a compound engine having the same physical dimensions, the efficiencies would be about 20 per cent greater than those shown in Fig. 1. If this locomotive is assumed to be running in service where the average speed is 40 m.p.h.* and if the firing rate is 100 lb. of coal per sq. ft. per hour, the fuel consumption will be 0·08 lb. per trailing ton-mile† when working simple, and 0·066 lb. per ton-mile when working compound. Sir Henry Fowler (1933) has given the values 0·083 and 0·068 lb. per ton-mile respectively as the fuel consumption to be expected from simple and from compound engines. The curve of Fig. 1 may therefore be regarded as representative of modern British practice. It can be used immediately to calculate the performance of a steam locomotive of given dimensions. Without serious error we can take the horse-power output as constant at medium and high speeds, as long as the firing rate is kept constant. The tractive effort at standstill is given by the well-known formula

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* Abridged version of a paper which was awarded the Coopers Hill War Memorial Prize and Medal for 1934.

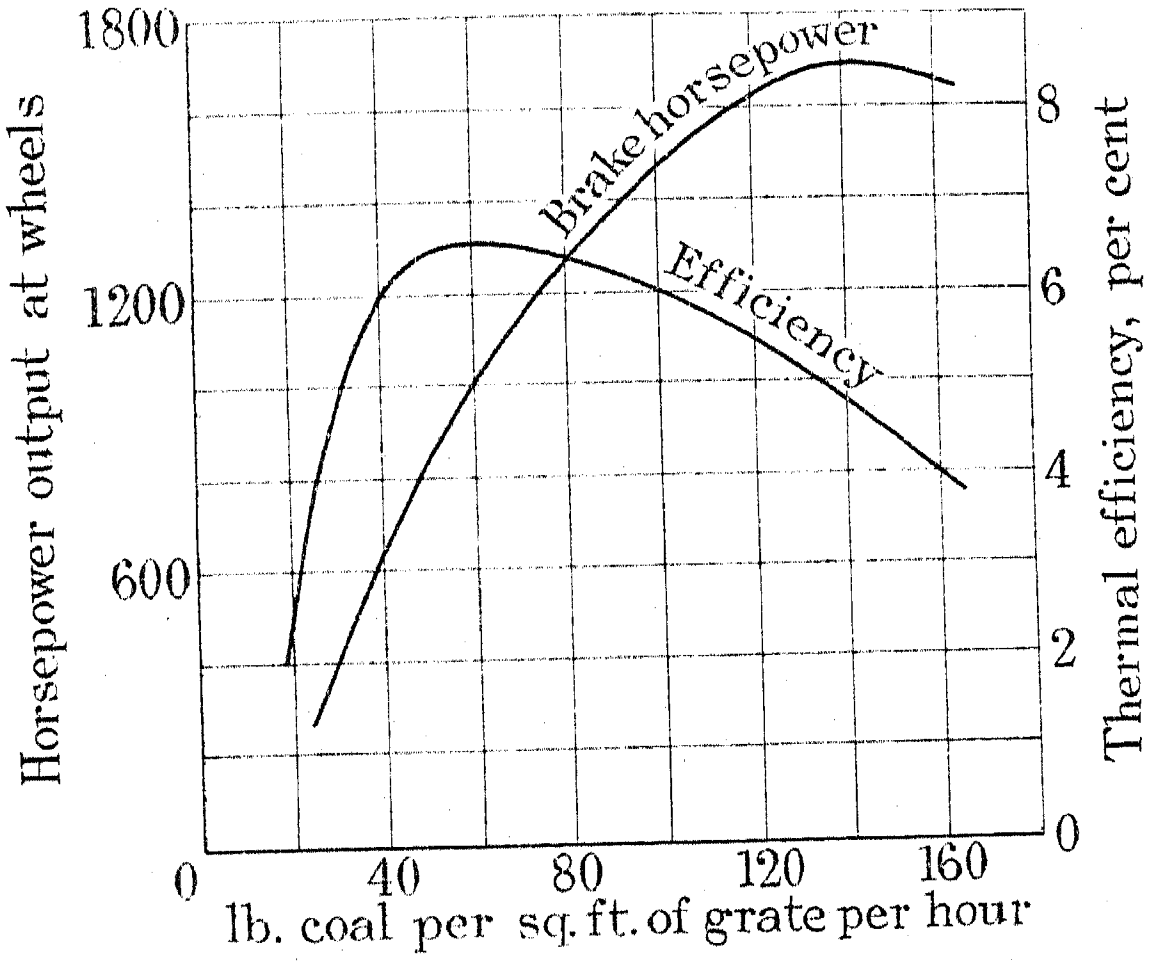

FIG. 1.—Brake horse-power and efficiency curves for simple expansion superheated locomotive.

$$T = kd^2\frac{PS}{D} \text{ pounds}$$

where d is the cylinder diameter in inches, P the boiler pressure in lb. per sq. in., S the stroke in inches, and D the driving-wheel diameter in inches. The constant k is variously taken at from 0·65 to 0·85, depending on the cut-off, but for comparison with electric locomotives the value 0·85 is used here. The dimensions and weights of some modern British locomotives are given in Table 1. To compare the performance of steam locomotives of this kind with that of equivalent electric locomotives, the speed/tractive-effort curve for the first locomotive shown in this table, the L.M.S. "Pacific" type, is shown in Fig. 2. This characteristic was calculated on the assumption that the horse-power output is constant. Actually, the output of a steam locomotive at a constant firing rate decreases somewhat as the speed increases, due to wire-drawing of the steam, etc., but this loss of power is relatively small. This locomotive has an output of approximately 1 650 h.p. at the driving wheels. The weight of the engine, excluding the tender, is 122 tons, giving a weight of 148 lb. per horse-power. When the weight of the tender is included, the weight per horse-power becomes approximately 200 lb.

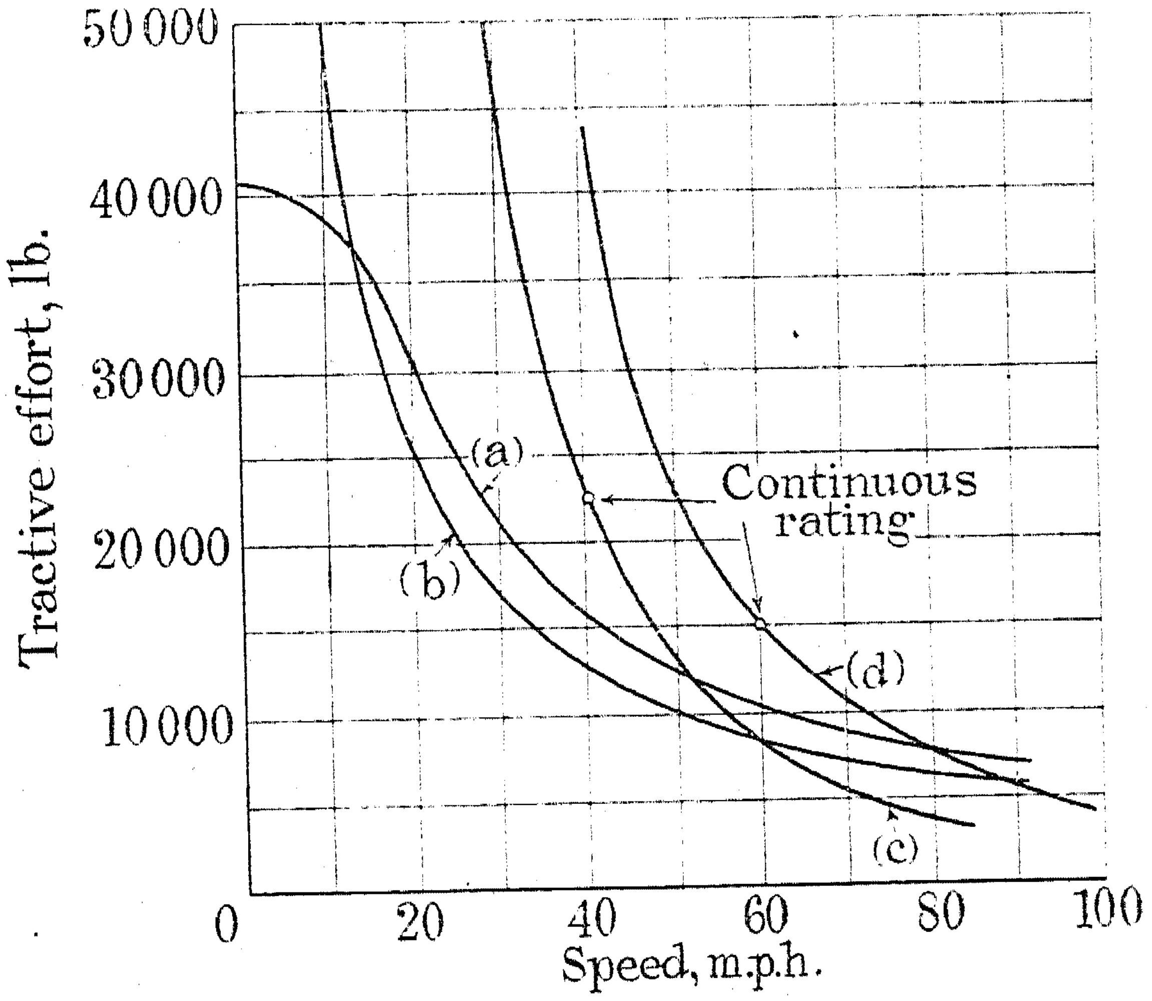

FIG. 2.—Speed/tractive-effort characteristic of rail tractors.

(a) Steam locomotive, 122 tons excluding tender.
(b) Diesel-electric locomotive, 120 tons.
(c) Electric locomotive, 120 tons. Continuous rating at 40 m.p.h.
(d) Electric locomotive, 120 tons. Continuous rating at 60 m.p.h.

The possibilities of increasing the weight efficiency of the steam locomotive seem to lie in the direction of higher steam pressures, superheating, compounding, and more efficient combustion.

The combustion rate of locomotive furnaces is already considerably greater than that found in stationary practice, and an improvement in fuel consumption therefore implies an increase in firebox grate area. The tendency to-day is in this direction, following American practice, where grate areas of 80 to 100 sq. ft. are common. However, since greater power is usually of more importance to a railway than greater economy, it is found that the use of large fireboxes is accompanied by longer boiler tubes, larger heating surfaces, and in general by larger locomotives, with no startling improvements in either weight efficiency or fuel consumption. It is not intended to give the impression that there has been no advance in steam locomotive design in recent years; it must be recognized, however, that the improvements noted recently consist principally in refinement of a rather imperfect machine, by the addition of superheaters, feed-water heaters, and so on. In these respects locomotive practice has followed stationary practice. Modern stationary water-tube boilers, however, using steam pressures up to 1 000 lb. per sq. in., and temperatures approaching the critical, show no immediate adaptability to locomotives. We must therefore conclude that future progress will follow the trend of the past, in the direction of heavier locomotives, with the addition of refinements such as boosters, automatic stokers, etc., but with slow improvement of weight efficiency.

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* Requiring 52 800 ft.-lb. of work per ton-mile, using Aspinall's train-resistance values.

† Whenever the word "ton" occurs in this paper, the short ton of 2 000 lb. is intended. For railway mechanics this is convenient, as the gravity force on a grade of 1 in g is then simply 2 000/g pounds per ton, and the inertia force for 1 mile per hour per sec. acceleration, allowing for rotational inertia, can be assumed with small error at 100 lb. per ton. Calculations are thereby simplified.

(*b*) *Oil-Electric Tractors.*

Recognizing these limitations of the steam locomotive, the development of electric traction motors, in conjunction with improvements in heavy-oil engines, has led to the introduction of the oil-electric locomotive as an improved form of self-contained tractor. In its present state of development, the oil-electric locomotive suffers from the same disadvantage as the steam locomotive, namely, that its weight efficiency is very low, and in addition that its power output is definitely limited by the capacity of the engine. It is very difficult to define the capacity of an oil engine, and, limiting consideration to the Diesel type, we find that the rated output is determined largely by the conservatism and judgment of the designer. We can, however, arrive at an index of the capacity of a Diesel engine of given dimensions from considerations of the combustion in the cylinder. If we assume that 14·62 lb. of air are required to burn 1 lb. of fuel completely, which would be the case if the oil contained 87 per cent carbon and 13 per cent hydrogen, then an engine cylinder of, say, 503 cub. in. capacity, working on the 4-stroke cycle at 750 r.p.m., would be capable, without supercharging, of burning 1·09 lb. of fuel per minute. The heat in this fuel is the maximum which can be utilized for conversion into work without changing the dimensions of the cylinder.

TABLE 1.

Modern British Steam Locomotives.

Railway	L.M.S.	L.M.S.	L.N.E.
Wheel arrangement	2–C–1	2–C–0	2–C–1
Cylinders	4	3	3
Cylinder dimensions	16¼ × 28 in.	18 × 26 in.	20 × 26 in.
Wheel diameter, in.	78	81	80
Steam pressure, lb./sq. in.	250	250	180
Grate area, sq. ft.	45	31·2	41·25
Water-heating surface, sq. ft.	2 713	2 081	2 930
Superheating surface, sq. ft.	370	445	525
Weight on drivers, tons	80·6	70	67·2
Total weight (excluding tender), tons	122·1	95	103·5

In general, if A is the piston area in sq. ft., v is the piston speed in ft. per min., n is the number of strokes per working cycle, and H is the heat content of the fuel, in B.Th.U. per lb., and assuming 1 cub. ft. of free air to weigh 0·0727 lb., we have

$$\text{B.H.P.} = \frac{Av}{n} \times \frac{0{\cdot}0727}{14{\cdot}62} \times \frac{778H}{33\,000} \times K \quad . \quad . \quad (1)$$

for the maximum horse-power obtainable from a Diesel-engine cylinder, K being a constant. Substituting in this formula the appropriate values for B.H.P., A, v, and n, for any particular engine, we can determine a value of K for that engine, which is a measure of the product of the thermal efficiency and the utilization of the cylinder space. For average conservative designs, K is usually between 13 and 16 per cent; supercharging of the intake air may increase K to 20 per cent. For railway work, 16 per cent seems to be the most usual value for K, for both 2-cycle and 4-cycle engines. The piston speed v may vary from 1 000 to 1 800 ft. per min., without greatly affecting the value of K. Formula (1), then, enables us to get an approximation to the output to be expected from an engine of given cylinder size, and, applying this formula, we at once see the reason for the poor weight efficiency of the high-power Diesel tractor.

TABLE 2.

Diesel-Engine Outputs.

Cylinder size (diam. × stroke)	Piston speed	Number of cylinders	Output	Speed	Relative generator weight
in.	ft./min.		b.h.p.	r.p.m.	per cent
4 × 4	1 500	6	190	2 250	100
5 × 5	1 500	6	300	1 800	125
6 × 6	1 500	6	430	1 500	150
8 × 8	1 500	6	760	1 125	200
10 × 10	1 500	6	1 200	900	250

In Table 2 are shown theoretical horse-power output figures for Diesel engines, working on the 2-stroke cycle, for sizes from 190 h.p. up to 1 200 h.p. The horse-power output increases approximately with the square of the cylinder diameter, but the speed of rotation decreases in inverse proportion to the length of the stroke, and no saving in weight is obtained by increasing the size of the engine; in fact the weight efficiency of a large engine is inherently worse than that of a small engine. The exact weight per horse-power will vary between different manufacturers. If electric transmission is used (which appears to be imperative in railway work) the weight efficiency of the generator decreases very rapidly as the engine size is increased. On the basis that the D^2l constant is the same for all sizes of Diesel-electric locomotive generators, the last column of Table 2 shows approximately how the weight per kW of the generator increases as the engine size increases. This, of course, is entirely due to the lower speed of the larger machines. For a Diesel-electric locomotive to compete with the steam locomotive, an output of something like 1 200 to 1 800 h.p. at the wheels is necessary for important main-line work. The larger output requires either two 900-h.p. engine-generator sets, or a greater number of smaller units. The former has the advantage of simplicity, but the weight efficiency is so poor as to show no advantage over the steam locomotive. The latter alternative theoretically shows a better weight efficiency, but it seems that the practical problem of building a locomotive in which are installed a number of small generating sets can be solved only at the expense of complication of the control and power circuits, with a resulting high maintenance cost. The actual maintenance cost of Diesel-electric locomotives in main-line service is not known with any precision. There are only about 100 Diesel locomotives in service having an output of more than 300 h.p., and a large fraction of this number is in shunting service, the maintenance cost of which varies widely from place to place. The general statement may be made, however, that the maintenance cost of a Diesel locomotive should not exceed that of a steam locomotive.*

For a comparison with steam and electric locomotives, the performance characteristic of a Diesel-electric locomotive, of 120 tons weight, is shown in Fig. 2, on the basis of a weight efficiency of 180 lb. per h.p. at the rim of the driving wheels. Such a tractor would develop about 1 350 wheel h.p. over most of the operating range. Owing to the method of speed control usually employed, the power would be somewhat less than this at low speeds, and, on account of the inherent characteristic of the series traction motor, at high speeds the full engine output would not be absorbed by the motors, and the horse-power would drop in the highest speed-ranges also. Essentially, however, the Diesel locomotive is a constant-horse-power machine, and suffers from the limitations of such tractors during the accelerating period.

(*c*) *Electric Tractors.*

The preceding sections briefly indicate the principal factors which limit the power output of a self-contained locomotive, whether of the steam or the oil-electric type. In both these types, the output of the prime-mover is the maximum of which the locomotive is capable. In the electric locomotive, on the other hand, the prime-mover may for practical purposes be considered to have an infinite capacity. If the "power limit" of the distribution circuit is high enough, then the limitation to the output of an electric locomotive is the inherent characteristic of the traction motor.

The physical performance of the electric tractor is shown by the curve for a 120-ton locomotive in Fig. 2. Depending on whether great power output is required at high speeds for express running, or at lower speeds for frequent-stopping service, or for hauling heavy trains at moderate speeds, it is possible to adapt the same locomotive in both cases by an adjustment of the gear ratio. The series traction motor is not a constant-output machine; the power delivered decreases very considerably as the speed increases. The speed at which the required power is to be delivered can, however, be decided in advance, and the gear ratio between the motors and the driving wheels arranged accordingly. For this reason an electric locomotive can always be applied to give its optimum performance.

The only limitation of the electric tractor is its ability to transform the energy drawn from the contact line. In any traction system depending on adhesion, the tractive effort exerted by the tractor must not exceed the coefficient of friction times the weight on the driving wheels. This adhesive limit to the tractive effort is utilized by the electric traction motor to a greater extent than by any other railway equipment. The maximum tractive effort is exerted from standstill up to relatively high speeds, but at some definite speed, depending on the size of the motor, the tractive effort begins to decrease quite rapidly.

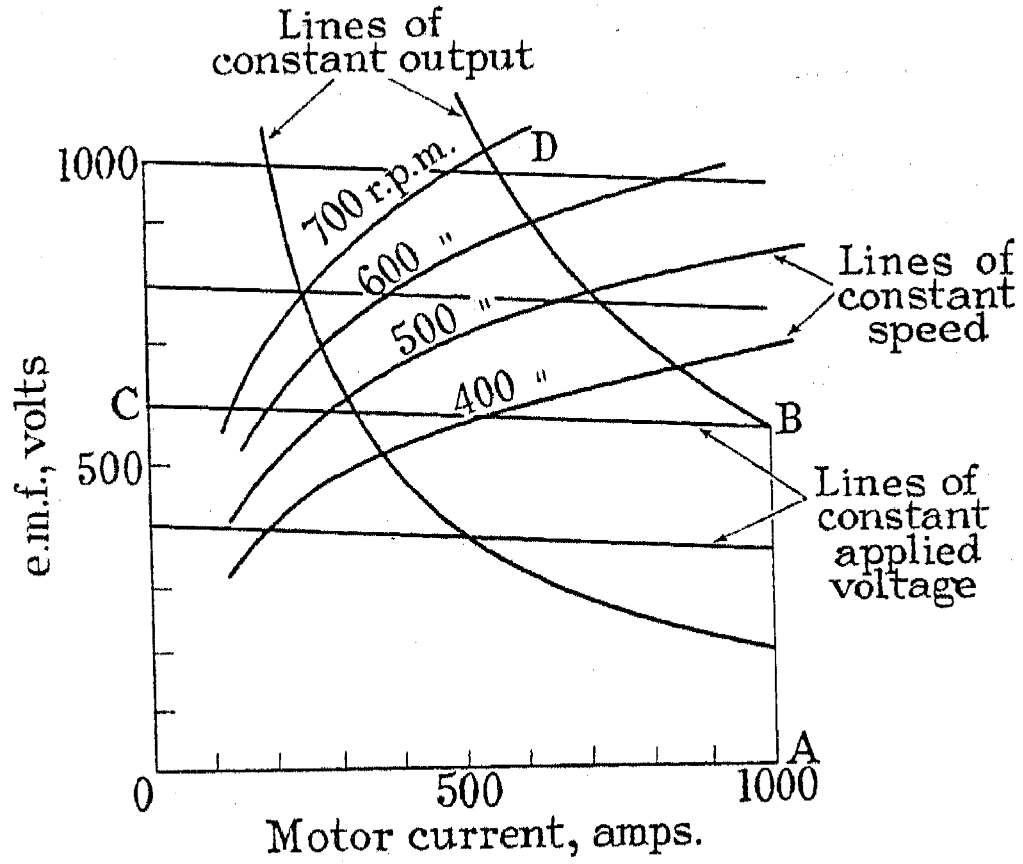

FIG. 3.—Characteristic curves of series traction motor.

Fig. 3 shows the characteristic properties of a d.c. series traction motor. This curve shows the relation between current and voltage for the three cases of (*a*) constant horse-power, (*b*) constant applied voltage, and (*c*) constant speed. If E is the generated back-e.m.f., R the resistance of the motor, V the applied voltage, and I the current, we have the fundamental equation

$$E = V - RI \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Plotting the curve of this function we get the lines of constant applied voltage, such as CB. The universal method of starting an electric train is to apply a voltage such that the current on the first notch is something below that required to slip the driving wheels. The voltage is then raised by successive steps, until full line voltage is applied across the motors. This process is shown diagrammatically by the line AB in the figure. The load on the motors during this period is principally the inertia of the train, and consequently the speed of the motors will thereafter increase, as shown by the line BC, the voltage being maintained constant. The output of any motor is *EI* watts, and at any voltage this is clearly a maximum when the current is a maximum. In Fig. 3, for example, if A represents the maximum current, and AB represents the back-e.m.f. with 600 volts applied, then the maximum output occurs at the point B. The line BD shows how the voltage must vary as the current decreases, if the horse-power is to be maintained constant at its maximum value. The actual performance of the motor, as represented by the line BC, falls very far short of this. Translated into terms of train operation, this means that an electric locomotive will have excellent accelerating characteristics up to a certain speed, but that thereafter the tractive effort will rapidly decrease. In a d.c. locomotive there are three things which prevent us from designing a motor to maintain its output up to the highest speeds, namely, (1) commutation, (2) heating, and (3) line voltage. With present designs of traction motors, the average voltage between commutator bars is between 15 and 20 volts. The lower this figure can be made, the more stable the design will be. Unless the ratio of field ampere-turns to armature ampere-turns is made fairly high, field distortion is likely to raise the potential between individual bars to 40 or 50 volts. To design a motor to reach its maximum horse-power at 600 volts, say, and to attempt to raise that voltage to 1 000 volts, so as to maintain the maximum horse-power up to higher speeds, will then obviously raise commutation difficulties. In actual practice the motor voltage cannot be raised above the line voltage, except by boosters, but the effect of an increased terminal voltage is obtained by field-weakening. There is a limit to the extent of field-weakening, determined by the allowable ratio of armature ampere-turns to field ampere-turns. If this ratio is exceeded, trouble from flashing motors is likely to arise. It would seem that considerable advantage could be derived from the use of compensating windings. In stationary practice it is usual to place a distributed compensating winding on all machines over 300 kW, and when this is done it is possible to withstand even short-circuits without flashing. The use of compensating windings on traction motors would allow considerably greater field weakening at high speeds without jeopardizing commutation.

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* See G. V. LOMONOSSOFF: "Diesel Traction," *Proceedings of the Institution of Mechanical Engineers*, 1933, vol. 125, p. 537.

The 870-h.p. (continuous) motors of locomotive E502 of the Paris–Orléans railway are, to the author's knowledge, the only traction motors equipped with compensating windings. On these motors it is possible to reduce the field ampere-turns to 26 per cent of the full field values, as compared with 43 per cent in the case of non-compensated motors of the same design.

The second limitation, that of heating, can be overcome by the use of forced ventilation. Forced cooling has always been standard on a.c. traction motors, but in d.c. service has been used only on the largest equipments. On the motors mentioned above, each motor has an external fan, supplying 3 540 cub. ft. of air per minute to the motors. This is an important factor in obtaining a high rating from a given frame. As design improves, heating always becomes the ultimate limitation, and it is probable that forced ventilation will become standard for d.c. traction motors in railway service. The third limitation mentioned above, that of line voltage, is not at present a serious one. Present methods of railway operation do not require a very high output at high speeds, at any rate in Great Britain, where trains are relatively light. In the United States, however, where trailing loads of 5 000 tons are common, the necessity for higher speeds with these trains is coming to be realized, and electric locomotives in heavy freight service will be required to maintain their maximum output up to high speeds. In such locomotive applications it is desirable to raise the motor voltage as the motor current decreases, when the train accelerates. With d.c. traction the possibility of doing this economically seems to depend on the use of a motor-generator or booster control. The use of additional rotating machines in the locomotive is, however, undesirable, except perhaps in the case of mountain-grade electrification, where there is considerable advantage in using separately excited motors, making regenerative braking automatic. The only locomotives yet built which can maintain their horse-power output up to the highest speeds at which they can operate have been of the motor-generator type. The weight efficiency of these locomotives is rather low, however.

The limitations enumerated above do not apply with the same force to a.c. equipments. If a characteristic curve similar to Fig. 3 were drawn for an a.c. commutator motor, the constant-voltage lines CB would have a much greater slope, owing to the reactance of the motor. Consequently the disparity between the operation at constant voltage and the constant-output characteristic is not so great as in the case of d.c. motors. In addition, it is easy to put over-voltage taps on the step-down transformer, so as to raise the motor voltage at high speeds. This has a similar effect to the field-weakening of d.c. motors. The a.c. traction motor has the important inherent characteristic, therefore, of approximating to a constant-horse-power machine and, when compared with a d.c. motor of similar rating, is capable of greater schedule speeds when the distance between stops is fairly large, involving periods of high-speed running.

The following discussion will apply to the simple series a.c. commutator motor, with commutating poles, as modern a.c. traction motors are almost exclusively of this type. In Fig. 4 is shown a main field pole of a traction motor, with two armature coils short-circuited by a brush. There are three e.m.f.'s to be compensated during the commutating period: (1) the e.m.f. due to rotation of the coils undergoing commutation in the armature-reaction field, (2) the e.m.f. due to reversal of the current in the coils undergoing commutation, and (3) the transformer e.m.f. due to the alternations of the main-field flux. The coils short-circuited by the brushes act as the secondary of a transformer, the main field winding being the primary. This e.m.f., if uncompensated, causes large circulating currents between the brushes and commutator bars, with resulting sparking and burning of the commutator. Formerly, the resistance-lead motor was a common design, the object being to limit the circulating currents to a safe value. This design has been abandoned, however, and at present all a.c. traction motors are fitted with commutating poles. The resistance-shunted interpole has become almost universal, on account of its simplicity and cheapness. Fig. 5(*a*) shows how this design is connected, and Fig. 5(*b*) is a vector diagram showing how the transformer and rotational e.m.f.'s are compensated.

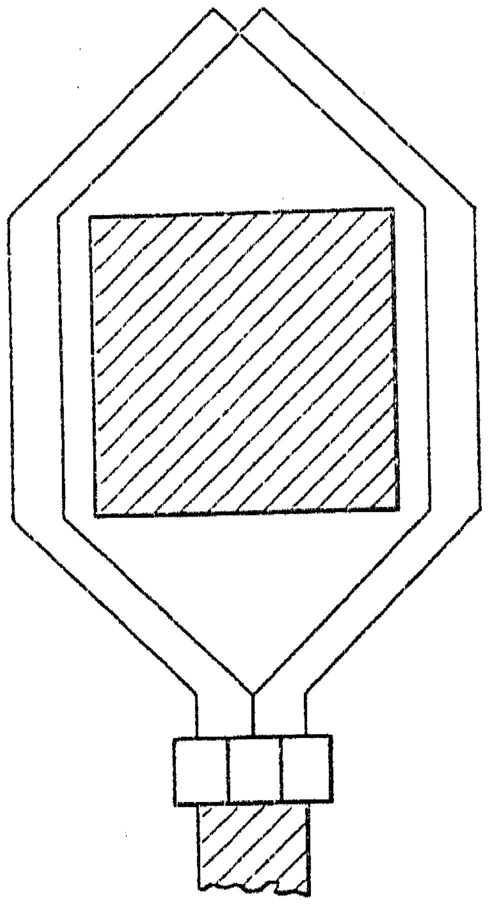
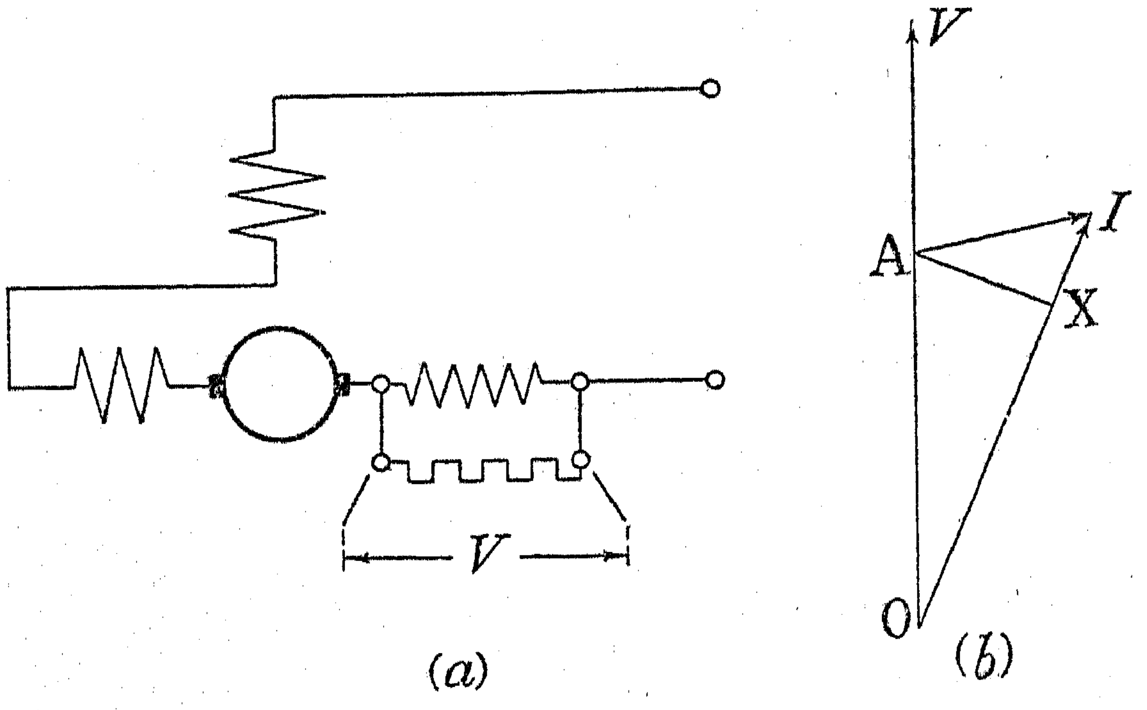


Fig. 4.

In this diagram OV represents the voltage across the interpole and resistor, while OA is the current through the resistor. OI is the total motor current, so that AI is the current through the commutating winding. The current AI may be resolved into two components: AX, 90 degrees out of phase with the motor current OI, and XI in phase with this current. The former is in the correct phase relation to compensate the transformer e.m.f. in the coils short-circuited by the brushes, while the latter compensates the rotational e.m.f. At any value of the motor current the transformer e.m.f. is constant, regardless of speed; the neutralizing voltage, however, is proportional to the speed of rotation, and it is therefore evident that at each value of the current the transformer e.m.f. is perfectly compensated only at one speed. Actually it is not necessary to compensate perfectly, since a certain voltage between bars is necessary to maintain an arc. Sparkless commutation is therefore obtained over a wide range of operation. This is shown in Fig. 6, which gives the relation between the neutralizing e.m.f. and the transformer e.m.f. at constant current, as the speed changes due to notching-up on the controller. At standstill, however, it is impossible to neutralize the transformer e.m.f. by means of the commutating poles, and it is then necessary to limit the main flux density to keep down the e.m.f. between the heel and toe of the brushes. This is the chief limitation to the output of the series-commutator type motor. It is frequently necessary in locomotive service, when starting a heavy train, for the locomotive to "lean on the load," exerting considerable tractive effort at standstill. If a voltage of over 2·5 is continuously applied between the heel and toe of a carbon brush, it will eventually become red-hot, and when in contact with a commutator the bars will be softened and pitted. The early work of Eschenberg and Latour, however, showed that in actual service a limiting voltage of 7 volts between the heel and toe of the brush is permissible without bad effects. This limits us to about 3 volts between bars, when the brush width is equal to twice the bar pitch. From these considerations we can fix the maximum output to be obtained from a given motor. As in the case of the d.c. motor, the output is *EI* watts, where *E* is the e.m.f. generated by the rotation of the armature. We have



(*a*) (*b*)

Fig. 5.

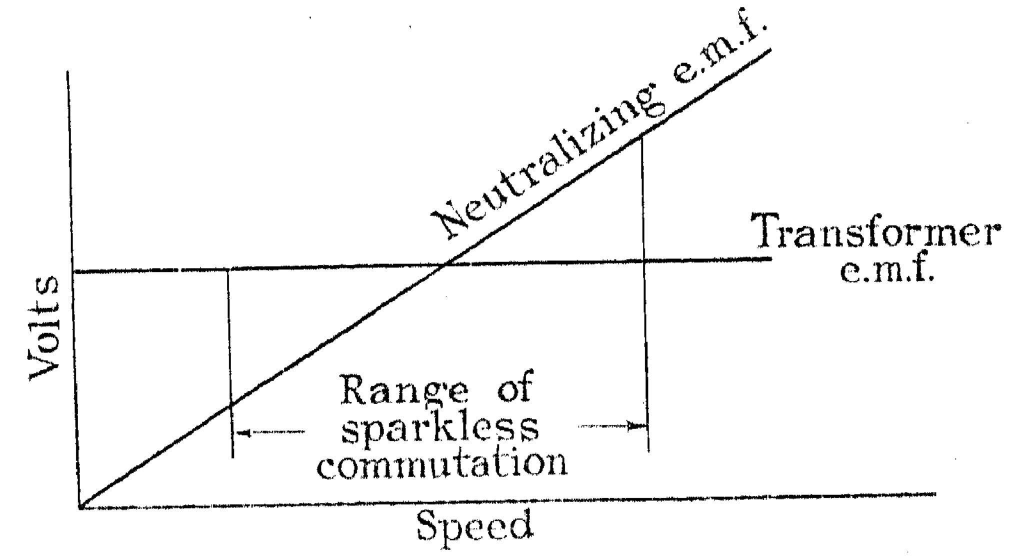


Fig. 6.

$$E = 4T \cdot \frac{np}{120} \cdot \frac{\phi_M}{\sqrt{2}} \times 10^{-2} \quad . \quad . \quad . \quad (3)$$

where T = number of turns in series between brushes, n = speed in r.p.m., p = number of poles, and ϕ_M = maximum value of the flux.

If P is the output, then

$$P = \frac{np\phi_M TI}{3\,000\sqrt{2}} \text{ watts} \quad . \quad . \quad . \quad . \quad (4)$$

If we neglect friction, windage, gear and bearing losses, etc., we also have the following expression for the output of the motor:—

$$P = \frac{\text{T.E.} \times \text{M.P.H.}}{0{\cdot}503} \text{ watts}$$

where T.E. is the tractive effort at the rim of the driving wheel, and M.P.H. is the speed of the locomotive in miles per hour. Equating this to (4), we get

$$\text{T.E.} = \frac{np\phi_M TI}{3\,000\sqrt{2}} \times \frac{0\cdot503}{\text{M.P.H.}} \text{ pounds} \quad . \quad . \quad (5)$$

The limiting features of a design are (1) the peripheral speed of the commutator, v feet per minute; (2) the brush current density, i amperes per square inch; and (3) the transformer e.m.f., e_t volts. We then have the following relations:—

$v = \pi Dn$ feet per minute.

$i = \dfrac{2I}{plw}$ amperes per square inch, where l is the active length of the commutator in inches and w is the brush width in inches.

$e_t = \sqrt{2}\pi fmt\Phi_M \cdot 10^{-2}$ volts, where f is the frequency in cycles per second, m is the number of coils short-circuited by a brush, and t is the number of turns per coil.

Using these relations, equation (5) reduces to

$$\text{T.E.} = \frac{vpilm\phi_M}{1\,402\,\text{M.P.H.}} \text{ pounds} \quad . \quad . \quad . \quad (6)$$

The maximum value of v, the peripheral speed of the commutator, in present-day practice, is 9 000 to 10 000 ft. per min. This speed corresponds to the maximum speed of the locomotive, and the ratio of the speed of the commutator to the speed of the train is a constant. The above expression can therefore be used to obtain the starting tractive effort. Tests have shown that the brush current density can be made as high as 150 amps. per sq. in., superimposed on a transformer voltage between commutator bars of 2·9 volts. The total transformer voltage between the heel and toe of the brush can therefore be 5·8 volts, when the brush width is twice the bar pitch. With one turn per coil this transformer voltage will limit the flux at starting to 2·6 megalines per pole at 25 cycles and 3·9 at 16⅔ cycles per sec. Substituting these values in equation (6), we get for the starting tractive effort:—

$$\text{T.E.} = 5\,000\frac{pl}{\text{M.P.H.}_{max.}} \text{ pounds at 25 cycles per sec.}$$

For a locomotive in passenger service the maximum speed would be perhaps 85 m.p.h. With 55 000 lb. on each driving axle, a starting adhesion of 25 per cent requires a tractive effort of 13 750 lb. per axle. With two motors per axle we should require, then, a 12-pole motor with a 9½-in. commutator, or a 16-pole motor with a 7-in. commutator. At 16⅔ cycles per sec. we could attain this tractive effort with two 12-pole motors per axle, each having an active commutator length of 6½ in.

The foregoing equations ignore the effect of commutating poles. Since the transformer e.m.f. can be effectively neutralized after the speed of the motor has passed a certain minimum, there is no reason for limiting the flux per pole to the low value required by starting conditions. It is therefore a common practice to limit the field current only at starting, by means of an inductive shunt or reactor in parallel with the field windings on the first few notches only, this reactor being cut out at higher speeds. By this means the horse-power developed by the motor can be increased about 25 per cent, while the reactor increases the weight of the motor equipment (transformer, motors, gears, and preventive coil) about 2 per cent, or frequently much less.

In this discussion of the limiting features of traction motors, attention is confined to consideration of the motors as transformers of energy. Regarded as such, it is possible to show that modern motors, whether of the d.c. or the a.c. single-phase type, are capable of excellent performance in service of the most arduous kind. In a practical application of electric tractors it is necessary, however, to keep in mind the limitations enumerated. The standard methods of engineering procedure take care of this, and a general paper on railway electrification does not demand a discussion of these methods.

The following sections will therefore be limited to a comparison of the performance of the tractors whose characteristics have just been presented.

(3) COMPARISON OF STEAM, OIL-ELECTRIC, AND ELECTRIC TRACTORS.

(a) *Weight and Cost of Tractors.*

The preceding analysis of the characteristics of the three common types of rail tractors permits a comparison of their values in rail transport on a physical basis. The analysis, in the case of steam and oil-electric tractors, was confined to locomotives, for the possibility of incorporating the traction apparatus in the coach structure does not offer great advantages with these tractors, except in branch-line and other unimportant service. With electric traction equipment, on the other hand, there is a great advantage in mounting the apparatus directly on the carriages themselves. The inherent characteristics of the equipment, of course, are the same whether the apparatus is mounted in this manner or in a separate locomotive.

We may list the approximate weight per horse-power of these different tractors as follows:—

(i) *Steam Locomotives.*

	Lb. per h.p.
Main-line passenger*	150 to 200
Express goods*	150 to 200
Suburban tank	180 to 250

(ii) *Oil-Electric Tractors.*

Locomotives, goods, and shunting	200
Locomotives, main-line	180 to 200
Equipment, total, for rail motor-cars	100

(iii) *Electric Tractors.*

	D.C.	A.C.
Passenger locomotives	80 to 120	80 to 120
Goods locomotives ..	100 to 135	100 to 135
Equipment, for mounting on coaches, complete	35 to 55	35 to 55

The weight efficiency, or specific weight per horse-power, of the Diesel-electric tractor, whose possibilities have aroused so much interest of late, is no better than that of the steam locomotive. In fact, for most of the locomotives built in the past, the weight per horse-power is rather more than that of a modern main-line steam engine.

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* Including tender.

Recent designs indicate the possibility of constructing a high-power Diesel-electric tractor for main-line service at a weight efficiency of about 180 lb. per h.p. Even this is not very attractive, however, particularly since the initial cost of a Diesel-electric locomotive is about twice that of a steam locomotive and at least as great as that of an electric. The Diesel locomotive has the advantage of greater availability than the steam locomotive, perhaps in some cases to the extent of offsetting the high initial investment. It also offers, in common with electric tractors, the possibility of using one-man engine crews in certain types of service. To the author's mind, at any rate, these advantages are not sufficient to warrant consideration of a wholesale substitution of Diesel tractors for steam, particularly in a country where fuel cost is not one of prime importance, and in a paper on railway electrification a close comparison between the characteristics of the Diesel-electric and the electric locomotive would be of no particular value. The wide field of economic use for the Diesel-electric tractor in branch-line service is of course recognized. The self-contained oil-electric rail car offers great possibilities for savings in light passenger service, but as such lines, where traffic is light, do not often warrant a study of electrification apart from main-line electrification, the application of Diesel traction to branch lines will not be considered.

The possibility of removing the limitations of the steam tractor has been discussed above. As regards the Diesel tractor, a reduction in weight and cost presents apparently insuperable difficulties. Compared with the electric locomotive, the weight per rated horse-power can of course never be as low. The weight of a railway Diesel generator set is about 45 lb. per h.p. for large-output sets, and to this must be added the weight of radiators, fuel tanks, auxiliaries, motors, and control. The weight of the total "electrical equipment" of an electric locomotive is usually under 55 lb. per h.p., so that it seems absurd to expect that the Diesel locomotive can ever be built as lightly as the electric. The cost of a quick-revolution Diesel engine, giving about 42 s.h.p. per cylinder, would be at the lowest about £2 10s. per h.p. when produced in quantity, and probably £5 per h.p. for ordinary rates of factory production.* To this must be added the cost of the electrical equipment, cab structure, and running gear. The electrical equipment for a Diesel locomotive will cost no less, and probably more, than that for an equivalent electric locomotive, while the mechanical parts will always cost more on a h.p. basis. The approximate present-day costs of steam, oil-electric, and electric locomotives are approximately as follows:—

	Cost per h.p.	Cost per lb.
(i) Steam: †		
Main-line passenger ..	£4 10s.	$8\frac{3}{4}$d.
Standard goods ..	£11 0s.	8d.
Suburban tank ..	£9 10s.	10d.
(ii) Oil-electric (at least) ..	£16 10s.	20d.
(iii) Electric (d.c.):		
Mechanical equipment..	£1 11s.	
Electrical equipment ..	£5 10s.	
Total	£7 1s.	16d.
(iv) Electric (a.c. single-phase):		
Mechanical equipment..	£1 11s.	
Electrical equipment ..	£7 0s.	
Total	£8 11s.	20d.

These figures show that, as regards first cost, the electric locomotive compares rather unfavourably with steam, and the first cost is, of course, not the only factor to be considered in putting it to work, as allowance must be made for the cost of the substations and track equipment incident to electrification. When the factors of availability and low maintenance cost are taken into account, this cost differential is in many cases offset by the operating savings. Consideration of this aspect of the cost of electric tractors is taken up below under the heading "Effect of traffic density."

(*b*) *Comparison of Performance of Rail Tractors* (*Suburban Service*).

The curves of Fig. 2 show to some degree the superior performance of the electric locomotive, but to complete the comparison it is necessary to investigate the characteristics of the different tractors in actual railway service. The specific weights tabulated above permit such a comparison to be made. It is not possible, in a reasonable space, to deal with all phases of railway traffic, and this discussion will therefore apply only to suburban passenger traffic, where the superiority of the electric tractor is most marked. In this service high schedule speeds are required, with very frequent stops. The distance between stations may be between $\frac{1}{2}$ mile and $1\frac{1}{2}$ miles. This is the most arduous type of passenger service a railway is called upon to handle, and on electric railways it is invariably taken care of by multiple-unit coaches, where the traction apparatus is mounted directly on the coach body. The service on underground railways is a special and very severe case of suburban passenger traffic.

For the haulage of main-line express trains, the electric locomotive shows its superiority over the steam locomotive in the greater power per ton of weight, which allows heavier trains to be hauled, and in the inherent characteristic of the traction motor (shown in Fig. 3) which makes it assume an overload when the speed is reduced due to grades and inertia forces, permitting greater average speeds to be maintained. When electric multiple-unit cars are used, the physical performance of the electric tractors becomes so superior to that of steam tractors that no fair comparison is possible. On "heavy traction" railways, as distinct from tramways and light railways, the electrification of suburban lines has been by far the most widespread application of electric traction, and "it has been clearly established that the more rapid and better service has had in every case the effect of bringing about large increases in the traffic, a noticeable feature being the growth of the off-peak load and the increased inter-suburban traffic."*

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* L. F. R. Fell: "The Compression-Ignition Engine and its Applicability to British Railway Traction," *Proceedings of the Institution of Mechanical Engineers*, 1933, vol. 124, p. 3.

† *Ibid.*

* Weir Report.

If we investigate the size and weight of the tractor required to haul a train of given net, or available,* length at a given schedule speed, we at once see the superiority of the electric multiple-unit train over other types of rail transport machines. In Fig. 7 is shown the schedule-speed characteristic of a typical electric passenger train using multiple-unit coaches. The schedule speed, which includes an allowance of 20 sec. for station stops, is plotted as a function of the distance between stations. To perform this service requires a tractor capable of a continuous output of 8 h.p. per ton of total train weight, including the weight of the tractor itself. The effect of this requirement on the total length and weight of the train is shown in Table 3. Four cases are considered, as follows:—

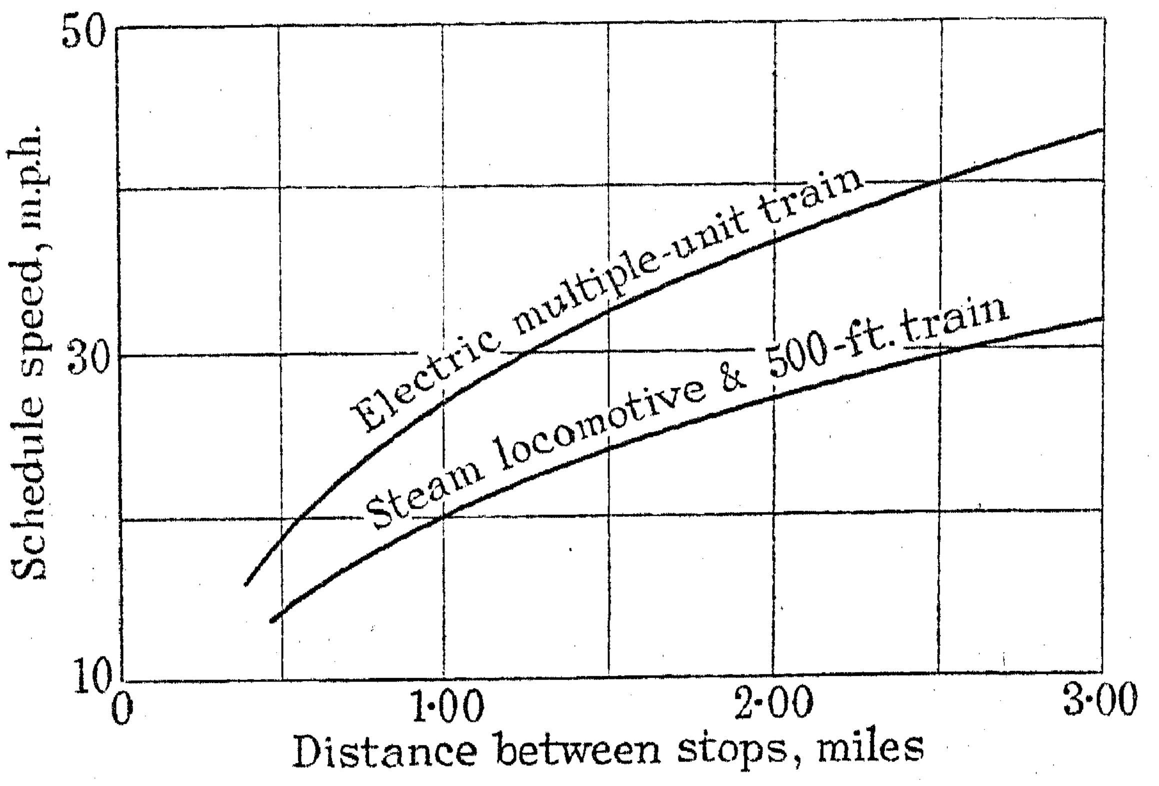

Fig. 7.—Relation between schedule speed and distance between stops. Level track; 5 per cent speed margin.

Table 3.

Type of train	Electric (multiple-unit)	Electric (multiple-unit)	Steam locomotive	Oil-electric
H.P. per ton	8	8	8	8
Weight of coach body and trucks, per ft. (lb.)	1 400	750	1 200	1 400
Passengers and load, per ft. (lb.)	175	175	175	175
H.P. per available foot	7·64	5·55	13·76	15·25
Total weight per available foot (lb.)	1 975	1 150	3 440	3 815
Total length for 100 ft. of available length (ft.)	100	100	170	151

(i) *Conventional multiple-unit equipments.* The coaches in this case are assumed to weigh 1 400 lb. per ft., which is somewhat above the weight of ordinary passenger coaches, to allow for the extra weight of the trucks and underframe to carry the electrical equipment.

(ii) *Light-weight multiple-unit equipments.* This column applies to the extremely light-weight trains which have recently been put in service in Germany and the United States.

(iii) *Steam-locomotive-hauled trains.* In this column steam locomotives are assumed to weigh 150 lb. per h.p. at the wheels, which is a lower limit to the specific weight.

(iv) *Oil-electric equipments.* This applies to oil-electric drives using Diesel engines, the engines and generators being built into the coach body. Oil-electric equipment usually occupies 1 ft. of space for each 25 h.p., so that the available length of the train is very much reduced when this type of equipment is installed. Oil-electric traction apparatus, including the engine, generator, motors, and control, weighs about 100 lb. per h.p. at the driving wheels, and when the weight of the coach body occupied by the equipment is added we find that the weight efficiency is little better than that of steam locomotives.

The fantastic size and weight of the steam or oil-electric tractor required to duplicate the service which electrical equipment can easily perform accounts for the remarkable success of electric traction in suburban service. From the third column of this table we see that a steam train, having an available length of 500 ft., would require a locomotive of 6 880 h.p., weighing 513 tons, to duplicate the schedule speeds shown for multiple-unit trains in Fig. 7.

For a comparison more in accord with actual facts, the performance of a steam locomotive hauling a train 500 ft. long is plotted in Fig. 7. The locomotive is assumed to have 150 000 lb. total weight on the driving axles. It is seen that the electric train is capable of a schedule speed approximately 35 per cent greater than this steam train. The schedule speed of an electric multiple-unit train is independent of the length of the train, whereas the performance of a steam train is directly affected by the number of coaches hauled. This, of course, assumes that the ratio of motor-coaches to trailers in the electric train is constant.

(*c*) *Comparison of Rail Tractors* (*Main Line*).

For the haulage of main-line freight and passenger trains, locomotives are almost always employed. In this service rapid acceleration is of relatively small importance, since the distance between stops is usually quite large. The rate at which an accelerating train acquires kinetic energy may therefore be quite moderate, and we find that the locomotive horse-power per ton of train weight is usually between 1 and 5, instead of between 8 and 10, as in suburban service. Hence there is no difficulty in applying sufficient power to the train, regardless of the type of locomotive used, unless the trailing load is very heavy indeed. In suburban service the superior performance of the electric motor often necessitates its use, regardless of other considerations.

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* That is, the total train length minus the length taken by the tractive equipment.

In main-line haulage, on the other hand, the economic problem is foremost. Since the mechanics of traction in main-line traction differ in no essential respect from suburban traction, we shall omit a particular discussion of locomotive performance and proceed to a consideration of the economics of main-line haulage.

(4) Economic Aspect of Electrification.

(a) *Permissible cost of Electrification as a Function of the Equivalent Gradient.*

To offset the high initial cost of electrical tractors, it is necessary to show operating savings with electric operation sufficient to pay not only the charges on the cost of electric rolling stock but also those on the distribution system and power supply apparatus. In order to determine the economic feasibility of electric traction, we must obviously have some idea of the permissible cost per traffic unit of the total work necessary for initiating an electrification project. In addition to the substations and contact lines, the principal subsidiary work connected with an electrification project is usually as follows:—

(i) *Distribution Circuit* (d.c. traction):—
  (a) Changing signals from d.c. track circuits to a.c. track circuits.
  (b) Mitigation of electrolysis effects.

(ii) *Distribution Circuit* (a.c. traction):—
  (a) Modification of signal-track circuits to operate as single-rail d.c., or change over to a.c. track circuits.
  (b) Mitigation of inductive interference with communication circuits.

(iii) *Track* :—
  (a) Increasing clearances for overhead catenary at over-bridges and tunnels.
  (b) Providing clearance for third rail (where used).
  (c) Removing overhead wires to provide clearance for catenary structures.

(iv) *Rolling Stock* :—
  (a) Provision of storage tracks.
  (b) Provision of maintenance and inspection facilities.

The expenditures for these works can easily run into very large figures, and careful analysis is necessary to keep the total cost within reasonable bounds.

Suppose that the profile of a railway is such that the work done by a locomotive in travelling from one end of the line to the other is the same as if there were a constant adverse gradient γ. As a first approximation we may assume the average train resistance to be made up of two parts, one due to friction which is independent of the gradient γ, and another due to gravity which is proportional to γ. The total resistance per ton hauled is then $R = a + b\gamma$ pounds, where a and b are constants. The principal items of the cost of transportation affected by a conversion to electric working are: (1) Fuel cost, denoted by e_f pence per ton-mile. (2) Crew wages, e_c pence per ton-mile. (3) Repairs and maintenance of locomotive, e_m pence per ton-mile.

The fuel consumed in transporting a ton 1 mile on a grade γ will be proportional to the work done, that is the fuel cost will be

$$e_f = k_f\,(a + b\gamma), \text{ where } k_f \text{ is some constant.}$$

The wages of the crew may be considered as an approximation to be independent of the equivalent gradient, for when steep gradients are encountered the locomotives will be of large capacity, so that the number of trains required to move a given tonnage will be about the same as when the grades are more favourable. The repairs and maintenance costs of locomotives have been found to be closely proportional to the work they do, and this part of the cost will vary in the same manner as the fuel cost, that is

$$e_m = k_m(a + b\gamma) \text{ pence per ton-mile, } k_m \text{ being a constant.}$$

For steam haulage the total cost of the three items enumerated above will then be given by

$$E_s = e_c + (k_f + k_m)\,(a + b\gamma) \text{ pence per ton-mile} \quad (7)$$

When electrification is being considered, it is necessary to take account of the fixed charges in determining the economic value of the electrification. If interest is paid at 5 per cent per annum, and depreciation at 3·36 per cent (which will retire the investment in 20 years when interest is added to the sinking fund at 4 per cent), we must add to the operating cost an amount $0\cdot0836C$ pence per ton-mile, where C is the capital expenditure per ton-mile of traffic carried per annum. The cost of electric haulage will then be

$$E_e = e'_c + (k' + k'_m)(a + b\gamma) + 0\cdot0836C \text{ pence per ton-mile} \quad (8)$$

TABLE 4.

	Steam	Electric
Crew expense, per ton-mile ..	0·05d.	0·03d.
Fuel, per ton mile	0·025d.	0·025d.
Maintenance, per ton-mile ..	0·025d.	0·0112d.
e_c	0·05	0·03
k_f	0·0042	0·0042
k_m	0·0042	0·0019

The values of e_c, k_f, and k_m, will vary under different conditions, and the reduction in these items to be expected by electrification will also vary somewhat. For average British conditions we may assume without great error that the values in Table 4 will apply, considering the average to cover all classes of traffic.

The permissible expenditure, per ton-mile of trailing load, for electrification, is found by equating (7) and (8) and solving for C. If we assume a to have the value 6, and that $\gamma = 0$, then using the values in Table 4, the permissible capital expenditure per ton-mile of traffic is given by $C = 0\cdot405$d. per ton-mile carried per annum. If, for example, the traffic density on a railway were 3 million ton-miles per mile of track per annum, the maximum allowable expenditure for electrification would be £5 070 per mile of running track. When the equivalent gradient increases, the capital expenditure allowable for electrification becomes much larger. Assume, for instance, that the equivalent gradient is $\gamma = 0 \cdot 005$, and $b = 20$ lb. per ton, and that the traffic density is again 3 million ton-miles per mile of track. The economic capital expenditure for electrification then becomes 0·61d. per ton-mile, or £7 630 per mile of running track.

(b) *Effect of Traffic Density on the Economic Value of Electrification.*

This approximate analysis indicates that electrification should be a paying proposition if the whole conversion can be carried out for something of the order of £5 000 to £8 000 per mile of running track, in cases where the traffic density is of the order of 3 million trailing ton-miles per mile of track per annum. To complete a study of this kind it is necessary to carry this approximation somewhat further, first to estimate more closely the reduction in maintenance and crew expense which accrues from a conversion to electric working, and second to investigate the actual cost of an electrification project, to see whether the work can be carried out for an expense of the order of magnitude quoted as being economical.

The ton-mile haulage cost is a function of the train weight, and it is of interest to see how this variation occurs, and its effect on the question of electrification.

Consider a hypothetical double-track railway route, 100 miles long, the ends of which are at the same elevation and on which the weight of the trailing load is limited by ruling gradients of 1 in 150, and assume that the average speed is limited by an average equivalent gradient of 1 in 250. In the case of steam traction this means that the total expenditure of work will be the same as if there were an actual adverse gradient of this magnitude, for the potential energy acquired during the ascent of grades is largely dissipated during descents, when the brakes must be applied to limit the speed. With electric traction, regenerative braking may be used, so that the dissipation of energy during descents is no more than at any other part of the run, being limited to the iron and copper losses in the motors, and the power taken by auxiliaries in the locomotive cab.

Each year a certain loaded tonnage must be moved from one end of this line to the other, and the empty wagons must be hauled back. Suppose the equipment must be capable, on a day of maximum traffic, of handling a tonnage 33⅓ per cent greater than on an average day, and, further, that the whole of this maximum movement must take place in an 18-hour day. If such a railway is faced with the alternative of purchasing new and more powerful steam locomotive equipment, or of converting to electric working, at what traffic density will it become more economical to adopt electric traction?

Considering only the main-line haul, with no allowance for the cost of shunting, ballasting train service, and so on; the costs of the construction work and of operation are tabulated in Tables 5 and 6 for steam and electric working. Four cases are considered, with different values of the tonnage to be moved per day, shown by A, B, C, D, in the tables. These costs do not apply to any particular system; nevertheless, they are capable of attainment in an actual project and are not very different from what could be obtained under average British conditions.

The figures in Table 5, for electric haulage, apply to a single-phase a.c. system. There are objections to the use of d.c. traction for heavy freight traffic, with respect to both the distribution system and the locomotives, which tends to make d.c. traction under such conditions costly to install and somewhat unsatisfactory in operation. These points are dealt with elsewhere in this paper.

The assumptions made in preparing the figures of Table 5 were fundamentally as stated above. With regard to the individual items of this table, the following basic assumptions were made regarding costs and so forth:—

Item (3): The allowable trailing load is assumed to increase as the tonnage to be handled increases, since a heavier traffic density will generally make the use of larger rolling stock desirable, in order to keep the ratio of tare weight to loaded weight as low as possible.

Items (4), *and* (5), *and* (6): The average speed of travel is arbitrarily assumed at 30 m.p.h., and the locomotive horse-power determined by assuming the trailing load to be hauled at this speed against a gradient of 1 in 250. The locomotive weight is assumed to be 100 lb. per continuous h.p.

Item (9): The total energy consumption is referred back to the point of supply, with an allowance of 15 per cent for stand-by losses.

Item (12): The track substations are assumed to be of the auto-transformer type, for a 3-wire distribution circuit. The cost of such substations, including installation, circuit breakers and control, should be less than £2 10s. per kVA of capacity.

Item (13): The catenary structures, catenary, and bonding, are assumed to cost £1 650 per single track mile. For a simple 3-wire distribution circuit, this is probably on the high side. This is analysed in more detail later in this paper.

Items (14) *and* (15): An allowance of £800 per single track mile is included to cover the cost of converting to a.c. track circuits for signal operation, and the change to telephone and telegraph circuits is assumed to cost £400 per mile of route. These figures may be high or low, depending on actual conditions. For instance, if all communication wires happened to be already in cable, there would probably be no expense for the latter item.

Item (17): The electric locomotives are assumed to cost 1s. 8d. per pound, for single-phase locomotives.

Item (21): The maintenance of electric locomotives will vary with the work they do, and may be assumed to vary in proportion to the horse-power rating. The cost per locomotive-mile is taken at 2d. for the smallest locomotives, increasing to 4·4d. for the largest. The 1 500-volt locomotives of the L.N.E. Railway have been costing about 1d. for repairs, and 0·5d. for shed charges, per locomotive-mile; or about 1·35d. per mile per 1 000 h.p. Figures for a.c. equipments show that it should be possible to maintain and repair single-phase locomotives for almost exactly this cost per mile per 1 000 h.p. The maintenance costs in the table are therefore of the correct order of magnitude.

Item (22): For the simple distribution lay-out possible with the 3-wire system, it is possible to maintain all lines and substations, including superintendence and operation from a central dispatching point, for an annual expense not exceeding that shown in the table.

TABLE 5.

Cost of Electric Working for Heavy Goods Traffic.

	A	B	C	D
1. Trailing tons per day, average (loaded)	7 500	15 000	22 500	37 500
2. Trailing tons per day, maximum	10 000	20 000	30 000	50 000
3. Trailing load per train, tons	1 000	1 600	2 000	2 500
4. Average speed of travel, m.p.h.	30	30	30	30
5. Locomotive weight, tons	77	124	154	170
6. Locomotive horse-power (continuous)	1 540	2 480	3 080	3 400
7. Number of locomotives, no spares	4	5	6	9
8. Number of locomotives, including spares and "turn-around"	7	8	9	12
9. Energy per annum, millions of kWh	9·75	19·5	29·2	41·7
10. Locomotive-miles per annum	548 000	684 000	820 000	1 094 000
11. Total substation capacity, kVA	15 000	24 000	30 000	36 000
12. Cost of substations, £	37 500	60 000	75 000	90 000
13. Catenary and bonding, £..	330 000	330 000	330 000	330 000
14. Signal changes, £	160 000	160 000	160 000	160 000
15. Telephone and telegraph, £	40 000	40 000	40 000	40 000
16. Total track equipment, £	567 500	590 000	605,000	620 000
17. Locomotives, £	90 000	165 000	230 000	337 000
18. Changes to repair facilities, £	6 250	7 250	8 250	12 500
19. Engineering and miscellaneous, £	65 000	72 000	78 000	88 500
20. Total investment, £	728 750	834 250	921 250	1 058 000
21. Locomotive maintenance, £ per annum	4 500	9 000	14 000	20 000
22. Line and substation, £ per annum	8 250	8 250	8 250	8 250
23. Engine-crew expense, £ per annum	9 000	11 280	13 500	18 100
24. Energy, £ per annum	20 300	34 900	52 500	86 000
25. Other expenses at 1·5d. per locomotive-mile, £ per annum	3 400	4 250	5 080	6 760
26. Total operation, £ per annum	45 450	67 630	93 330	139 110
27. Interest and amortization, £	60 500	69 500	76 600	88 000
28. Total annual cost, £	105 950	137 130	169 930	227 110
29. Trailing ton-miles per annum, millions..	365	730	1 092	1 825
30. Cost per ton-mile, d.	0·0696	0·0452	0·0364	0·0297

Item (23): Engine-crew expense, including drivers' and firemen's wages, can safely be taken at 4d. per mile for goods traffic, assuming that there will be only one man per locomotive.

Item (24): Energy has been assumed at 0·5d. per kWh at the supply point for low-frequency single-phase power. This figure is probably conservative for countries where electric energy is cheap, in view of the simple construction required in the supply authority's substation.

Item (27): Interest is assumed at 5 per cent, and an additional 3·36 per cent on the total investment is added, which is sufficient to retire the whole investment in 20 years, assuming interest at 4 per cent on the sinking fund.

Item (29): This is for the total trailing ton-miles, including the empty-wagon movement back to the starting point.

Somewhat similar assumptions were made in tabulating the figures for steam working. With regard to items (4), (5), and (6), in Table 6, the locomotive horse-power was determined in relation to the weight on the assumption that steam locomotives, including the tender, weigh 200 lb. per h.p. In the figures for electric working, a size of trailing load was assumed which is normally that handled by an electric locomotive where the appropriate traffic density obtains, and the size of locomotive required to handle the load was calculated. In the case of the steam figures, on account of the poor weight efficiency of the steam locomotive it was considered better to assume a figure for the horse-power available for the trailing load, and to calculate the weight of the train and the locomotive itself. The power assumed to be available at the locomotive drawbar in the various cases was:—

7 500 tons per day: trailing loads of such size as to require 1 000 h.p. at drawbar.
15 000 tons per day: trailing loads of such size as to require 1 150 h.p. at drawbar.
22 500 tons per day: trailing loads of such size as to require 1 300 h.p. at drawbar.
37 500 tons per day: trailing loads of such size as to require 1 650 h.p. at drawbar.

TABLE 6.

Cost of Steam Working for Heavy Goods Traffic.

	A	B	C	D
1. Trailing tons per day, average (loaded)	7 500	15 000	22 500	37 500
2. Trailing tons per day, maximum	10 000	20 000	30 000	50 000
3. Trailing load per train, tons	778	898	1 025	1 282
4. Average speed of travel, m.p.h.	30	30	30	30
5. Locomotive weight, tons	112	132	150	168
6. Locomotive horse-power	1 140	1 320	1 500	1 680
7. Number of locomotives, no spares	8	13	17	22
8. Number of locomotives, including spares and "turn-around"	11	20	25	33
9. Coal per annum, tons	32 200	64 500	96 700	158 000
10. Investment for locomotives, £	92 300	198 000	281 000	416 000
11. Locomotive maintenance, £ per annum	14 500	29 200	43 700	64 800
12. Fuel and water stations, £ per annum	8 250	8 250	8 250	8 250
13. Engine-crew expense, £ per annum	24 640	43 000	56 300	74 600
14. Coal, £ per annum	20 000	40 200	60 200	98 800
15. Other expenses, £ per annum	4 350	7 550	9 920	13 200
16. Total operation expenses, £ per annum	71 740	128 200	178 370	259 650
17. Interest and depreciation, £ per annum	7 720	16 550	23 420	34 800
18. Total annual cost, £	79 460	144 750	201 790	294 450
19. Trailing ton-miles, per annum, millions	365	730	1 092	1 825
20. Cost per ton-mile, d.	0·0523	0·0476	0·0443	0·0387

Reference to Table 6 shows, for instance, that under the assumed conditions a drawbar h.p. of 1 000 requires a locomotive of 1 140 h.p., 140 h.p. being required to propel the locomotive itself. The following notes on the other items of Table 6 will explain those points which are not self-explanatory.

Item (10): The cost of steam locomotives is assumed to be 9d. per lb. For locomotives for this type of service the price in England to-day would probably be less than this. The assumption is of small importance, as the interest and depreciation on the initial expense of locomotives is only about 10 per cent of the total annual charges.

Item (11): As in the table for electric working, the maintenance cost is assumed to vary with the horse-power of the locomotive in a linear manner from 5d. for the 112-ton engines to 7·3d. for the 168-ton engines, per locomotive-mile. These figures are probably on the low side for locomotives in such service as this. On one English railway, 8-coupled steam locomotives in mineral hauling service cost 8d. per mile for repairs alone, and 3·5d. per mile for shed charges. However, for new equipment it may be assumed that the charges will not be so large.

Item (13): Engine-crew expense was taken at 8·5d.

per mile. This is approximately the present-day cost of engine-crew wages in goods service in Great Britain.

Item (14): Coal was taken at 15s. per ton. This is a high figure for those railways which purchase their coal at the mine, but where freight charges must be added it is probably not too large. The quantity of fuel was estimated on the basis of the work done by the steam locomotives, with an assumed thermodynamic efficiency and an allowance for stand-by losses. The cost for fuel per engine-mile then works out at 6·9d. On one of the English systems the cost of fuel in goods service (excluding shunting) is 6·8d. per mile, which indicates a good agreement.

Item (17): Interest and depreciation are based on 5 per cent interest and a 20-year life, giving a total fixed charge of 8·36 per cent, the same as the figure assumed for electric haulage.

The costs per ton-mile shown in Tables 5 and 6 are depicted graphically in Fig. 8. The costs per ton-mile there shown are for the total trailing ton-mileages, including both the loaded and the empty movement. For the assumed conditions, then, electrification becomes economical when the traffic density exceeds 3 million trailing ton-miles per mile of track per annum. The curves of Fig. 8 show how the ton-mile cost of transportation by steam traction decreases as the train weights increase. Very economical transportation is possible by steam where conditions are suited to the handling of traffic in heavy trains by powerful locomotives. Examples of this are found on some of the American railways, where freight traffic densities up to 12 million trailing ton-miles per mile of track per annum are dealt with in trains of 5 000 tons or so, at a haulage cost less than 0·03d. per ton-mile. But even where these favourable conditions obtain it is often economically possible to take advantage of electrification. Our approximate equation (8) for the allowable expense for electrification shows that the economic limit of the capital expense *per ton-mile carried per annum* does not depend on the traffic density. The expenditure per track-mile, therefore, may permissibly increase in proportion to the traffic density. Table 5, however, shows that the actual expenditure required to electrify a railway increases at a much lower rate than the traffic to be handled. The actual value of the fixed charges to be borne by each traffic unit is considerably less where the traffic is heavy than where it is light.

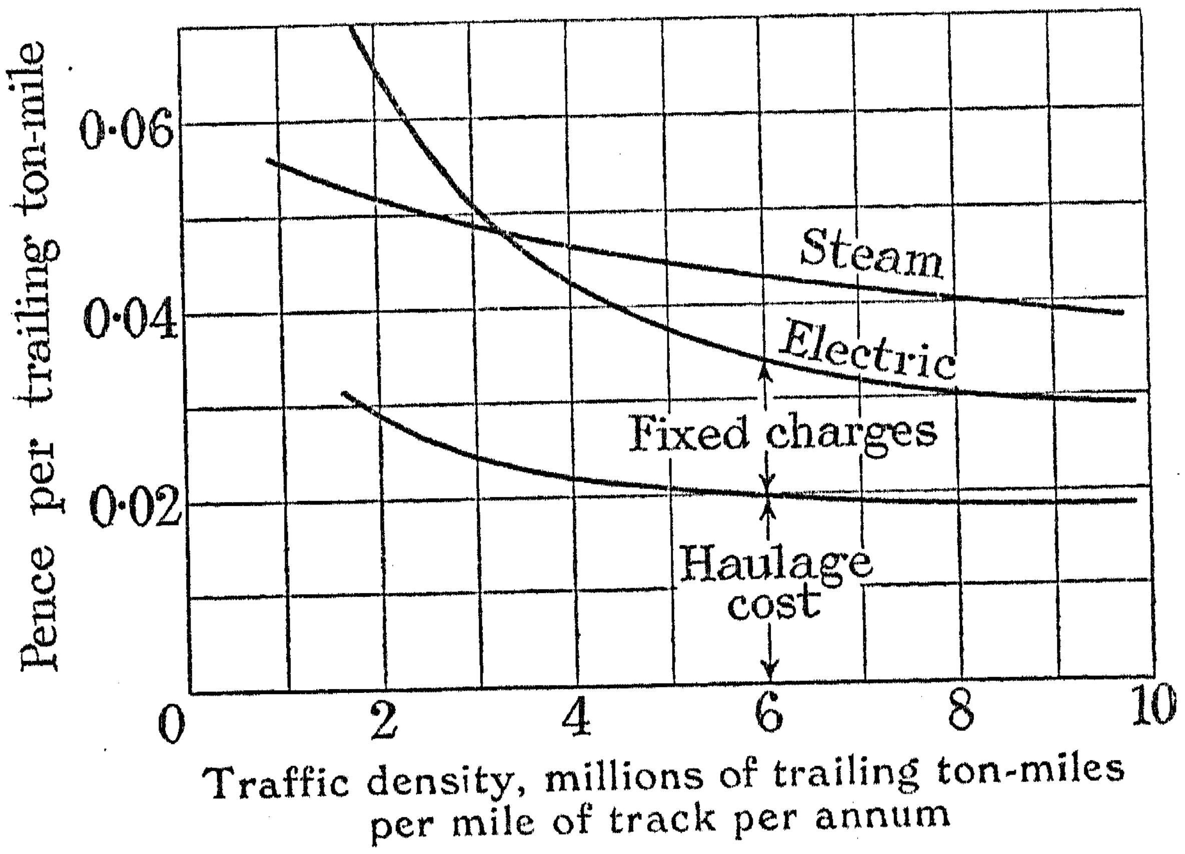

FIG. 8.—Effect of traffic density on cost of goods transport (from Tables 4 and 5).

For those items of railway operation directly affected by electrification, such as fuel, water, engine-crew wages, locomotive maintenance, etc., we usually find that in goods service the saving per ton-mile due to a substitution of electric locomotives for steam is between 0·015d. and 0·02d. per trailing ton-mile, depending on the cost of fuel and power, the rate of wages, and so on. This figure seems to be independent of the actual ton-miles produced and of the actual method of operation. If the haulage cost by steam is already as low as 0·03d. per ton-mile, it appears that a conversion to electric traction may reduce the operating expenses 50 or 60 per cent. A reduction of this magnitude is a reasonable expectation. On the Virginian Railway the maintenance charges and train-crew expense with electric traction are 66 per cent less per ton-mile than they were with the former steam operation. If steam-haulage costs are 0·06d. per ton-mile or more, however, which is a common figure for Great Britain, the adoption of electric traction cannot well be expected to reduce this cost more than 30 or 40 per cent. The statement that the saving per ton-mile due to converting to electric working is a constant, regardless of the method of operation, whether by small trains or large, is of course on the assumption that the train weights and rolling-stock capacity are the same before and after electrifying. If, however, conversion to electric operation is accompanied by a radical increase in the average trailing load, the savings with electric traction can become quite large. For example, a railway may be handling goods traffic by steam in trains of 300 tons, at an average cost per ton-mile of 0·06d. (cost of fuel, water, locomotive-crew expense, locomotive maintenance, etc.). Electrification would reduce this expense to about 0·04d. per ton-mile, but if the average train weight were increased to 1 000 tons—by no means a large train judged by standards abroad—this haulage cost might easily be further reduced to less than 0·03d. per ton-mile, an increase of 50 per cent on the gross return from electrification.

(5) CONCLUSION.

These considerations, taken in conjunction with the effect of train weights on the cost of transportation, indicate that the question of electrification cannot be considered apart from the operating policy of the transport system as a whole. The economic value of electrification has been shown to depend on the traffic density, and it has been shown that it is often economically feasible to take advantage of the superior qualities of the electric tractor.

A study of this nature shows that were a transport system to be developed *ab initio* in an advanced industrial country, such as Great Britain, electric working would be extremely attractive. In such a case, electrification could be made to pay even when the traffic density was quite low. Where a railway is already in existence, however, the capital cost of converting to electric haulage becomes of prime importance. The reason for this is perhaps not so much economic as financial.

The balance sheet of a railway company shows its principal liabilities to be its capital stock and its funded debt. The sum of these liabilities does not necessarily bear any particular relation to the value of the property, or to the earning power of the railway. Nevertheless, these liabilities constitute one of the principal charges against the earnings, and it is a very difficult matter to reduce them.

This financial situation has a direct bearing on railway electrification. To convert from steam to electric working entails heavy expenditures, but even so it is very often possible to show that the return on the investment is sufficient to show a profit, with a safe margin for amortization of the initial expense. However, the administrative body of a railway which is already carrying a heavy load of capital charges will hesitate before adding to it by converting to electric traction, particularly where there is not a very clear understanding of the inherent advantages of electrification, and this perhaps is the principal reason for the slow adoption of electrification.

It is recognized that for a transport system to work harmoniously there must be proper co-ordination between road, rail, and water shipment, of passengers and goods. This also has a direct bearing on the question of railway electrification, as it is only by having some conception of the relation of the parts of a transport system to the whole that the electric-railway engineer can integrate his work with the complete railway system.

The physical limitations of the electric tractor were discussed at the beginning of the paper, and it was shown that from this standpoint electrification shows very attractive possibilities. The principal question to be faced is that of reducing the initial expense for electrification, and this is primarily an engineering problem. The progress of electric traction therefore depends on the genius which engineers can bring to bear on the subject. The possibilities are almost unlimited, but there is an unfortunate tendency in engineering work for progress to carry with it over-refinement and complexity. This often results in increased cost. As a closing observation, the author would advocate, in traction work, a progress towards simplicity and cheapness.

APPENDIX.

THE CURRENT SYSTEM TO BE USED FOR ELECTRIFICATION.

(a) *Effect of the Distribution Circuits.*

The economic feasibility of railway electrification has been shown to depend on the traffic density. Equation (8) states mathematically that the total haulage cost per ton-mile increases in proportion, at any given traffic density, to the capital expended for electrification. Since the cost of the distribution circuits (including catenary, substations, and transmission) forms a large part of the total expense, this part of an electrification project calls for careful consideration in laying out the system. The associated works which were tabulated above, including electrolysis and mitigation of inductive interference, etc., depend very closely on the system of traction adopted. It is not possible, in a reasonable space, to consider even briefly the variation in the cost of this incidental work with different systems of electric traction. A general discussion of the single-phase and of the direct-current distribution systems, with regard to their physical and economic characteristics, is necessary, however, for an understanding of the factors on which the choice of a system depends.

Academically stated, the problem in laying out the distribution circuit is to obtain such a balance between the conductivity of the contact line and the capacity of the substations that the overall annual cost will be a minimum. The solution, of course, is also predicated on practical consideration, such as the permissible voltage regulation, the necessity for providing for a growth in traffic, and so on.

For a general scheme of railway electrification in Great Britain, only the 1 500-volt direct-current system has been seriously considered of recent years, and this system has been officially recommended for use in all main-line work. However, the 3-wire single-phase system, with 11 000 volts on the contact wire and 22 000 volts on the third, or balance, wire, at 25 or preferably 16$\frac{2}{3}$ cycles per sec., also seems to be ideally suited to British conditions. With train loads such as are usual in Britain, this system shows attractive possibilities for the construction of light and cheap track equipment.

The limitation of any distribution system for railway service is its "power limit," or the maximum power which it can deliver to the load. In this respect the 1 500-volt direct-current contact line imposes a definite upper limit on the quantity of traffic which can be handled by an electric railway. It is, of course, always possible to increase the power limit as traffic increases, by the installation of feeders, and by increasing the number of substations. Such a procedure is, however, costly, and in many cases difficult. It would seem more satisfactory to install initially a system having a high power limit, if this can be done without increasing the first cost.

(b) *Comparison of D.C. and A.C. Railway Distribution-Voltage Regulation and Substation Spacing.*

To obtain an approximate idea of the dimensions of a single-phase distribution circuit suitable for the traffic conditions of an average railway line in Great Britain, we may consider the hypothetical case of a double-track railway route, equipped to run on the 3-wire system. Under maximum traffic such a railway might require a load of 100 kW per mile of route, averaged over the whole length. Supposing the length of the electrified section to be 220 miles, what frequency-convertor and transformer-substation spacing is required to handle this load? The messenger and contact wire suitable for supplying the load, on the most liberal estimate, would not require more than 0·25 sq. in. of copper per track. We may, however, assume the use of bronze wires for the catenary, on a conservative basis, and allow the wires per track to be as follows:—

Catenary	
Messenger	37/·092 bronze, 67 per cent conductivity
Contact wire	6/0 S.W.G., 55 per cent conductivity
Balance wire	0·15 sq. in. copper
Earth wire	0·075 sq. in. copper

With a load concentrated midway between substations, the maximum power which can be delivered to the load by two adjacent substations is shown in Fig. 9 for both the d.c. and the a.c. cases. The curve for the single-phase case is for the unfavourable power factor of 0·6. The power factor of a well-designed single-phase motor at full voltage should exceed 0·9, but when starting a train with reduced line voltage the power factor may fall considerably below this.

The physical area of the wires over each track is in this case 0·625 sq. in., very nearly, while the total conductivity of all the wires is equivalent to that of about 0·48 sq. in. A suitable voltage for the system would be 11 000 on the contact wire, and 22 000 volts on the balance wire, giving a transmission voltage of 33 000. This arrangement of wires, it may be mentioned, is extremely conservative for the loads considered, and we could reduce all the sizes considerably without affecting the capacity of the system much.

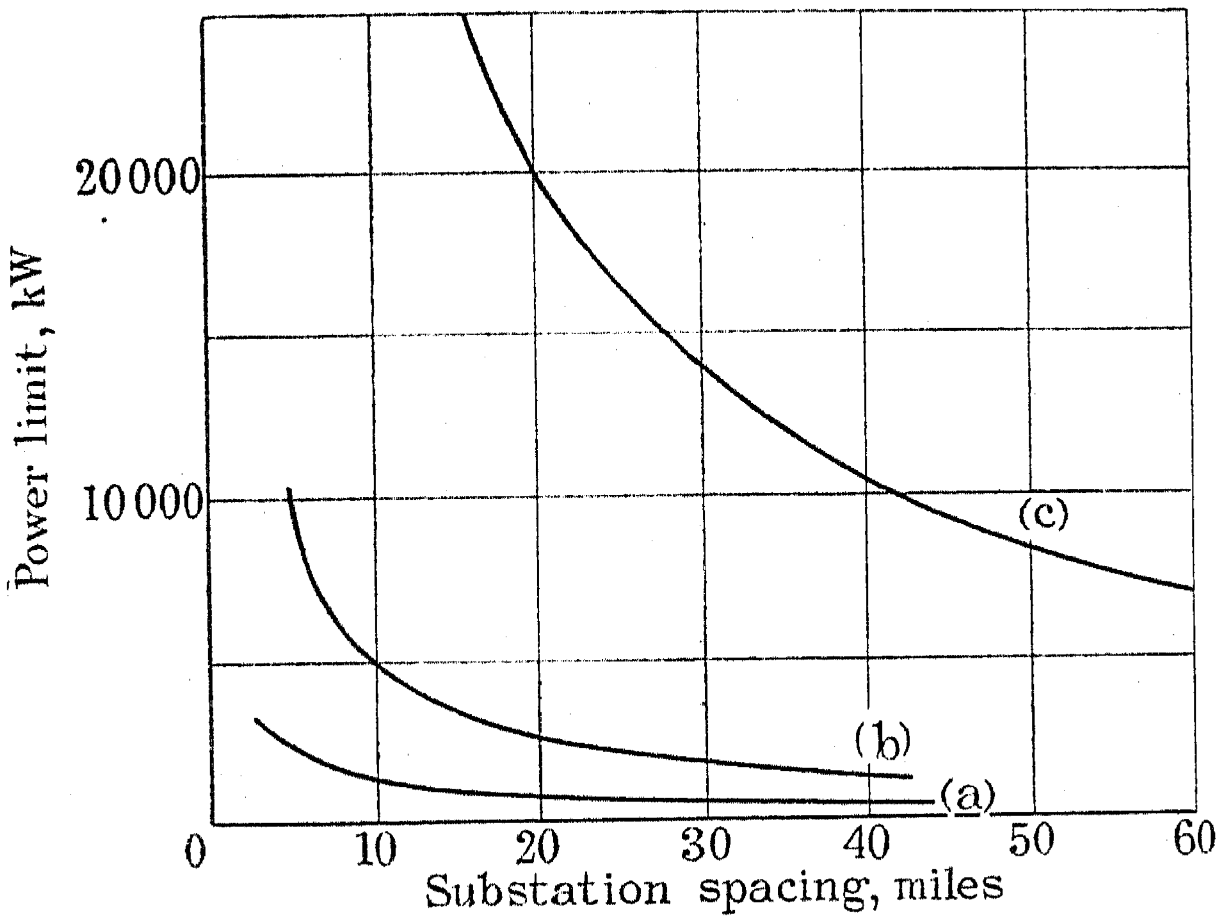

FIG. 9.—Power limit of contact lines.

(a) D.C., 1 500 volts.
(b) D.C., 3 000 volts.
(c) A.C., 11 000 volts, 25 cycles per sec., 0·6 power factor.

The question of substation spacing can be answered by referring to a paper by McGee and Harder.[*] They show that a system having characteristics similar to the above is capable of supplying 193 000 kVA-miles with 10 per cent voltage-drop at 0·7 power factor. This assumes that one balance wire is out of service. The average power factor on a single-phase railway using modern equipment should exceed 0·8, and on this basis our system will supply 154 000 kW-miles. If x is the distance from the nearest power-supply point to the end of the electrified zone, for a load of 100 kW per mile, we then have $154\,000 = 100\,x^2/2$, or $x = 55$ miles. The power-supply points, or frequency-convertor stations, may therefore be 110 miles apart and we shall require two points of power supply for the 220-mile route. The spacing of the track transformer substations may be determined from Fig. 10. The voltage regulation of the contact-rail circuit may be limited to 5 per cent when the total drop is 10 per cent at the extreme end of the electrified tracks. This condition can be met with a spacing of 20 miles between the auto-transformer stations.

Assuming the same conditions with a direct-current contact system at 1 500 volts but with copper conductors throughout, we find by the usual methods that for a voltage-drop of 10 per cent the substation spacing should not exceed 10 miles. A comparison of the two cases is as follows:—

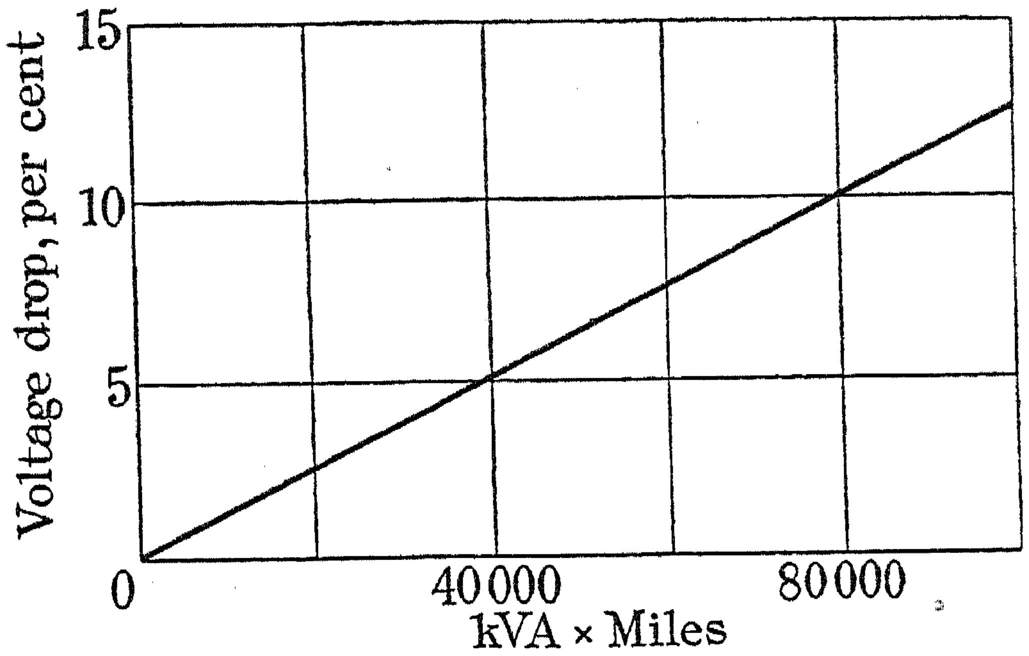

FIG. 10.—Voltage regulation of single-phase contact line; 25 cycles per sec., 0·6 power-factor. Values are for 11 000-volt trolley-rail circuit.

	D.C. 1 500 volts	A.C. 11 000 volts, 25 cycles
Total area of wires per track, sq. in.	0·625	0·625
Equi. copper area per track, sq. in.	0·625	0·48
Max. substation spacing for 100 kW per mile of route, two tracks, miles	10	20
Average voltage-drop, per cent ..	10	10 (max.)

With the 3 000-volt d.c. system the substation spacing may be increased to 20 miles with 10 per cent voltage-drop.

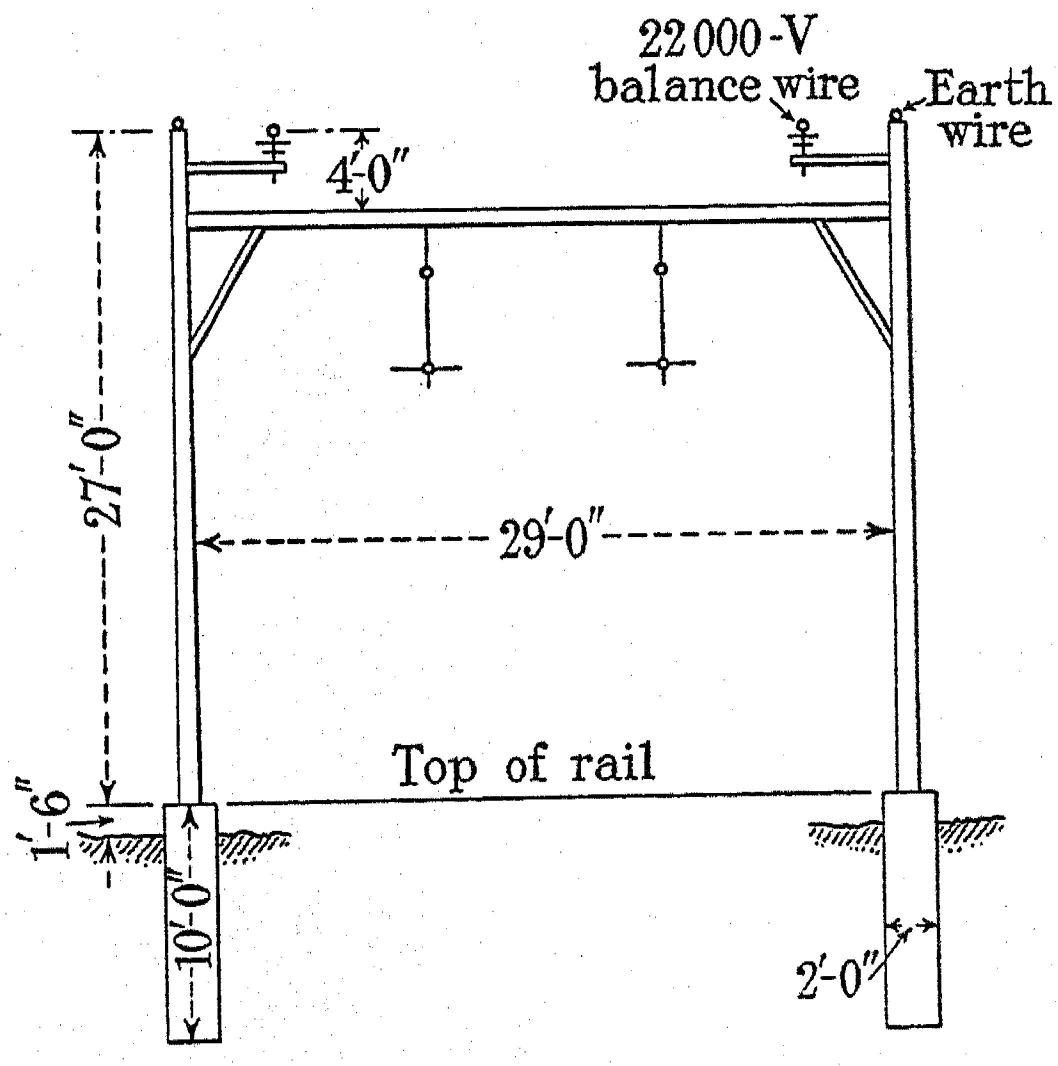

FIG. 11.

(c) *Cost of Catenary System.*

To apply the catenary to the railway it is necessary to provide suitable supporting structures. This part of the overhead system is often a great source of expense, but by careful design the cost may be kept within reasonable bounds. It is not necessary here to discuss the various means by which the cost of the catenary may be reduced, and we may assume a simple design of bridge, suitable for carrying the system referred to on page 840, such as that shown in Fig. 11. This would be suitable for a contact-wire height of from 16 ft. to 18 ft. To carry this system with an ice loading on all wires of ½ in. radial, plus a lateral wind load of 8 lb. per sq. ft. of projected area, and a simultaneous broken-wire load of 1 600 lb. at the top of the column, requires "side bearing" foundations 8 ft. 6 in. below the surface of the ground, 2 ft. square. If the top of the foundation is 1 ft. 6 in. above the surface of the ground, the volume of concrete required in each footing is about 1·5 cubic yards. This is on the basis of 5 000 lb. per sq. ft. allowable soil pressure at the base of the pier. With this soil pressure a gravity-type footing would require 3 cubic yards of concrete per column.

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[*] "Power Supply for Main-Line Railway Contact Systems," *Transactions of the American I.E.E.*, 1933, vol. 52, p. 364.

If the steel superstructure, under the conditions cited above, is to sustain a stress not exceeding 20 000 lb. per sq. in., the weight of the steel will not exceed 2 tons, made up approximately as follows:—

Columns	47 per cent
Beam	35 ,, ,,
Knee braces	7 ,, ,,
Base detail	9½ ,, ,,
Cross-arms	1 ,, ,,
Bolts, rivets, etc.	½ ,, ,,

The approximate cost per single-track mile of a catenary system using supporting structures similar to that shown in Fig. 11 is shown in Table 7.

TABLE 7.

Cost of 3-wire Railway Distribution System for 11 000-volt A.C. Contact Line.

	Cost per single-track mile £
Steel structures, 25 per mile. Material and erection..	300
Foundations, in place	220
Transmission wire, earth wire, and catenary	
Material	650
Labour and wire train expense ..	400
Bonding	80
Total cost per single-track mile ..	£1 650

(*d*) *Comparison of D.C. and A.C. Distribution Systems—Cost.*

We may use the figures in the preceding discussion to estimate the approximate cost of the complete distribution system. In comparing the cost of a d.c. distribution system with that of a single-phase system, it is necessary to distinguish two cases:—

(i) *Where power is purchased by the railway at one or two supply points, or is generated by the railway itself.* In this case the railway must build and maintain its own high-voltage transmission line to supply power to the track substations. If power is paid for on the 3-phase side, the cost of energy will be the same regardless of the system adopted, and the whole saving gained by the use of the single-phase system is in the initial capital expenditure.

(ii) *Where the power authority will supply power direct to the traction substations in the d.c. case; and at one or two points, at the single-phase frequency and voltage, in the a.c. case.*—Here the supply authority will either use existing transmission lines to get the 3-phase power to the substations, or will be required to build new lines in certain cases. With the single-phase system, the frequency convertors would probably be installed by the supply authority in existing e.h.t. substations, and there would be no investment required for transmission lines. In the U.S.A., where this method of supply obtains for both a.c. and d.c. traction, experience shows that the cost of power is usually somewhat higher for direct than for alternating current. If single-phase energy costs 0·5d. per kWh, d.c. energy will cost about 0·6d. per kWh (on the d.c. side). There are two reasons

TABLE 8.

Cost of Distribution and Substations.

220-mile route; 440-mile track.

Maximum load on system: 22 000 kW.

Total track substation capacity: 44 000 kW (100 kW per single-track mile).

(*a*) *Power purchased at supply authority's point of supply in both cases.*

	A.C. 3-wire 11 000/22 000 volts £	D.C. 1 500 or 3 000 volts £
(1) Frequency convertors, 30 000 kW @ £5	150 000	—
(2) Catenary and bonding, 440 miles @ £1 650	740 000	740 000
(3) Track substations, 44 000 kW ..	88 000	308 000
(4) Transmission line, 200 miles @ £1 700	—	340 000
Total	978 000	1 388 000
Difference	410 000	—

(*b*) *Power purchased at 25-cycle busbar in case of a.c. supply, and at d.c. side of track substations in case of direct current.*

	A.C. 3-wire 11 000/22 000 volts £	D.C. 1 500 or 3 000 volts £
(1) Catenary and bonding, 440 miles @ £1 650	740 000	740 000
(2) Track substations, 44 000 kW ..	88 000	308 000
Total	828 000	1 048 000
Difference	220 000	—

(*c*) *Cost of energy with alternative* (*b*) *above.*

	A.C. single-phase	D.C. 1 500 volts
(1) Load factor for 220 route-mile main-line railway, say	50 per cent	
(2) Annual energy consumption ..	96 500 000 kWh	
(3) Cost per kWh	0·5d.	0·6d.
(4) Annual cost of energy	£200 000	£240 000
(5) Saving with single-phase system	£40 000	—
(6) Capitalized value of saving at 5 per cent	£800 000	—

for this, first that considerable investment is always needed to get the 3-phase supply to the d.c. substations, which offsets the cost of the frequency-convertor sets, and second that the total substation losses in the d.c. case are much greater than the frequency-convertor losses in the a.c. case.

In Table 8 is shown a comparison of the investment required for a railway distribution system, between the single-phase system and the direct-current system. These figures are, of course, only approximate, as the effect of sidings, yards, etc., on the cost of the contact system has been ignored, and the load has been assumed to be uniformly distributed.

A double-track main-line railway line has been assumed, 220 route-miles long, on which the traffic density is such as to demand a maximum load of 100 kW per route-mile. The maximum load will then be 22 000 kW at the point of power supply. The diversity of a main-line railway load is usually such that the total capacity of the track substations is about twice the maximum load. The track substations will therefore have a total capacity of 44 000 kW. On these assumptions the comparative figures of the table have been compiled.

(1) *Cost of frequency convertors and substations.* The completely installed cost of converting equipment for 1 500 volts (d.c.) has been assumed to be £7 per kW of capacity. This cost will vary somewhat with conditions, but recent installations for 1 500 volts have cost between £6 10s. and £7 10s., and £7 is probably a good average. This figure would cover the complete substation, including buildings, automatic control equipment, and e.h.t. and d.c. switching.

Some indications are that the cost of 3-phase/single-phase frequency-convertor equipment, including switching and transformers, is roughly half that of a.c./d.c. convertors. This is probably so for units of large capacity, for a frequency ratio of 2:1, permitting high-speed sets to be used. The more conservative figure of £5 per kW of installed capacity used in Table 8 is probably nearer the actual cost for average conditions.

(2) *Catenary and bonding.* It is assumed that the figure of £1 650 per single-track mile will apply to both a.c. and d.c. contact systems. If the same total area of wire is installed in both cases, we may assume the a.c. system to use bronze wires for the catenary, with " inclined " catenary on curves, and the d.c. system to use all copper wires, with chord catenary on curves. In that case the a.c. system will be more expensive in respect of wires and insulators, but more economical in respect of steel, owing to the greater structure spacing on curves. The d.c. system will be more expensive in respect of line fittings (pull-offs, etc.) and structures, but economical in wire cost. The costs will not, therefore, be very different in the two cases.

(3) *Track substations for single-phase traction.* The arrangement of the substations, using auto-transformers, is inherently simple and cheap. The installed cost should not exceed £2 per kVA. Recent American practice has made use of high-speed breakers, to limit induction under transient conditions, and to limit damage at times of short-circuit. These breakers are extremely expensive, however, and where they are used the cost per kVA may easily exceed £2.

(4) *Transmission line for d.c. traction.* Assuming the power-supply points to be located at the same places as for the a.c. case, the transmission line must have sufficient capacity to transmit 149 000 kW-miles. At 33 000 volts, 3-phase, we require 0·15-sq. in. conductors to transmit this power, but the voltage-drop becomes 16·7 per cent. A transmission voltage of 66 000 gives sufficient capacity, but the construction is much more expensive. If we use 44 000 volts we find we can transmit the required power with a 10 per cent voltage-drop. A double-circuit 3-phase transmission line, installed on a railway right-of-way, could hardly be built for less than £1 700 per mile, and this figure has been used in the table.

It was mentioned above that the probable difference in cost between a.c. and d.c. locomotives is about £1·5 per h.p. Referring to the alternative (*a*) in Table 8, the saving consequent on using single-phase distribution is £410 000. This is sufficient to pay for the extra cost of 266 000 h.p. of single-phase locomotives, or, if the average h.p. is 1 500, of 177 locomotives. With alternative (*b*), we save £220 000 of capital, and if we add the capitalized extra annual expenditure for electric energy we get a total saving of £1 020 000. On the same basis this is enough to pay for the extra cost of 450 single-phase locomotives.

A notable feature of the a.c. distribution system is its low maintenance cost. The possibility of bronze catenary wires allows the simplest form of catenary construction to be used, on which, if properly designed and installed, the maintenance cost is almost negligible. The auto-transformer stations, of course, would be unattended, and the maintenance work to be done in such stations is always very small.

Locomotive maintenance was discussed elsewhere in this paper, and it was stated that the maintenance of modern single-phase locomotives, on a horse-power basis, is no greater than that of d.c. locomotives. The annual cost of substation operation and maintenance, and track-equipment maintenance, of a d.c. contact line such as that considered in Table 8, would probably be £85 per mile of track; for a single-phase line the cost would not, at the outside, exceed half of this, or about £42 per mile. The total maintenance saving due to the a.c. system on 440 miles of track is therefore £19 800 per annum, or about 2 per cent per annum on the total distribution investment.

The implication of these figures cannot well be ignored in any study of main-line railway electrification. The loads quoted in Table 8 are such as might be encountered on any British railway, and it would seem that the single-phase 3-wire system, at 11 000/22 000/33 000 volts, is very well suited to such loads, offering possibilities of a cheap, economically operated distribution system.

At the outset of this discussion of railway distribution it was mentioned that the subsidiary works to be undertaken in any scheme of electrification are frequently of great importance, and that their magnitude often depends on the system chosen for electrification.

In this comparison we have neglected this phase of the design of the transmission and contact system, but it is necessary, after having stressed the advantages of the single-phase system, to call attention to its great disadvantage, namely that with this system it is nearly always necessary to adopt means for preventing interference with neighbouring communication lines. This drawback was formerly considered serious enough to bar the use of the single-phase system in certain cases.

A review of the history of the subject shows that this objection was probably justified. In any engineering work it is desirable to predict results if a satisfactory final design is to be produced. Prior to the work of Carson and Pollaczek, the results of which were published in 1926, it was difficult to predict with any accuracy the inductive effects of single-phase earth-return circuits. Owing to the work of these investigators, however, it is now possible to calculate the effects of earth-return circuits in terms of the dimensions of the circuit and the soil conductivity. The method has been widely used in co-ordinating power and telephone circuits.

A discussion of the technical aspects of this problem is beyond the scope of this paper, but it may be mentioned that in those countries which use single-phase traction to any extent, inductive interference is regarded as a solved problem, and its technical aspect no longer influences the choice of a system for extension of the use of electric traction.

DIRECTIONS FOR THE MEASUREMENT OF THE POWER FACTOR OF CABLES AT POWER FREQUENCIES AND AT VOLTAGES UP TO 200 kV.*

[REPORT (REF. F/S4) OF THE BRITISH ELECTRICAL AND ALLIED INDUSTRIES RESEARCH ASSOCIATION.]

(*Paper received* 29*th May*, 1935.)

SUMMARY.

This report gives directions for the application of the Schering bridge to the measurement of the power factor of the insulation of cables at power frequencies and at voltages up to 200 kV. Details are given in Appendices of the principles of design of the air condenser recommended as a standard of reference, of subsidiary methods of power-factor measurement, and of the effect of wave-form.

The standardization of the Schering bridge method, as described, is recommended, and full details are given of the elaborate precautions necessary for shielding the cable and apparatus. The standard method provides for the measurement of power factors of the order of 0·01 to an accuracy of 0·0001 at a frequency of 50 cycles per sec., and at voltages up to 200 kV.

If one of the subsidiary methods is employed, the steps described herein should be taken to secure that the results agree with those obtained by the recommended standard method.

CONTENTS.

Definitions.

Directions.
- (i) Standard of reference.
- (ii) Standard circuit (Schering bridge).
- (iii) Shielding of connections and low-voltage arms of bridge.
- (iv) Shielding of cable.
- (v) Shielding of transformer for measurements with cable-sheath earthed.
- (vi) Evaluation of power factor and capacitance.
- (vii) Elimination of capacitance corrections.

Appendix I. Design of Air Condenser.

Appendix II. Subsidiary Methods of Measuring Power factor.

Appendix III. Effect of Wave-form.

DEFINITIONS.

Power factor is the ratio of the power absorbed to the product of the r.m.s. values of voltage and current, when the wave-form of the supply is sinusoidal.

Dielectric-loss angle is the angle by which the fundamental component of the current lags behind quadrature with the fundamental component of the voltage. The tangent of this angle is measured by the standard method given in this paper, and when less than 0·04 is equal to the power factor.

DIRECTIONS.

(i) *Standard of Reference.*

The standard of reference shall be a condenser having only air or nitrogen, at atmospheric or higher pressures, as dielectric. The condenser shall be provided with adequate shielding to prevent the measuring circuit from being influenced by any stray capacitance which may involve a current component not in quadrature with the voltage.

The principles of design of an appropriate air condenser are given in Appendix I.

(ii) *Standard Circuit* (*Schering bridge*).

The standard method of measurement shall be the Schering bridge having a basic circuit as indicated in Fig. 1, in which C_1 represents the cable and C_2 the standard air condenser. R_3 and R_4 are resistances, and C_4 is a condenser. Two of the quantities R_3, R_4, and C_4 must be variable.† V is a vibration galvanometer, which may be of either the moving-coil or the moving-iron type.

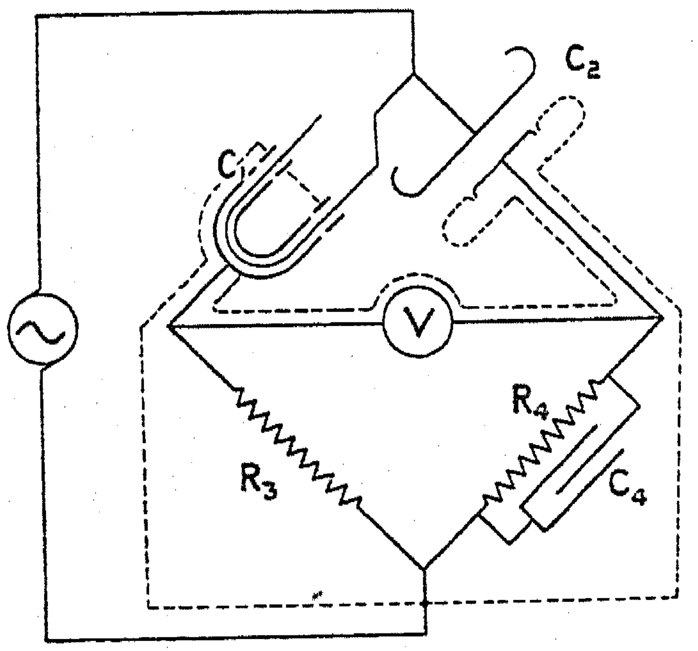

FIG. 1.—Basic Schering-bridge circuit.

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* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

† The product $R_4C_4\omega$ gives the power factor of the cable, where R_4 is expressed in ohms and C_4 in farads, and $\omega = 2\pi \times$ frequency. To enable the measuring circuit to indicate the power factor directly it is convenient to make R_4 constant and equal to 318·4 ohms for the standard frequency of 50 cycles per sec. R_3 may be replaced by a fixed resistance R_n, and a fraction of the voltage across it may be applied to the galvanometer by means of the resistances R_m and R_p (Fig. 2). The necessity for a variable resistance of heavy-current capacity for long lengths of cable is thus avoided.

(iii) *Shielding of Connections and Low-voltage Arms of Bridge.*

The connection from the air condenser to the measuring circuit must be protected from external electric fields by a metal tube or other screen.

The connection from the cable must be screened.

These two connections may be brought inside a wire-netting enclosure containing and screening all the low-voltage parts of the bridge. Alternatively all the low-voltage components and leads must be screened. If a moving-iron galvanometer is used it requires magnetic shielding in addition to electrostatic shielding.

(iv) *Shielding of Cable.*

Errors may arise from (1) surface leakage over the cable end, (2) distortion of the electric field near the end of the sheath, and (3) ionization of the air in the neighbourhood of the end by discharge from high-voltage conductors.

Accurate measurements may be made on lengths down to 1 yard if suitable guard rings are provided at the ends of the lead sheath, and if an efficient screen completely surrounds the portion of cable under test, and is connected to the guard rings. The length of the guard rings should be at least 8 times the thickness of insulation, and never less than 4 in. The guard ring may be formed by cutting a gap in the lead sheath or by wrapping metal foil on the stripped end of the cable. In cutting the lead sheath it is best to remove a strip 1 in. in width, cutting a smaller gap through the metallized paper. One layer of insulating paper is then wound on tightly, covering the edge of the metallized paper on one side. Metal-foil ribbon is next wrapped closely round the metallized paper on the other side and carried partly over the layer of insulating paper, thus leaving virtually no gap between the test piece and the guard ring. Oil-resisting tape is then bound tightly to fill and cover the gap in the lead sheath (Fig. 3). If metallized paper is not present, special care must be taken not to distort the lead. Metal foil is then wrapped round the insulation close to the lead. More metal foil is wrapped round the end of the lead and pressed over into the corners and in contact with that in the gap. The gap is completed as already described. The overlapping gap described should be used whenever practicable. In other cases the gap between the guard ring and the section under measurement should not be greater than $\frac{1}{16}$ in. When the cable under test is terminated with sealing ends, the losses over the porcelain can be eliminated by insulating the sealing end from the lead sheath, as shown in Fig. 4. If the sheath is earthed the sealing end must be mounted on an insulating plate. A guard ring inside the sealing end is also necessary when short lengths are being tested.

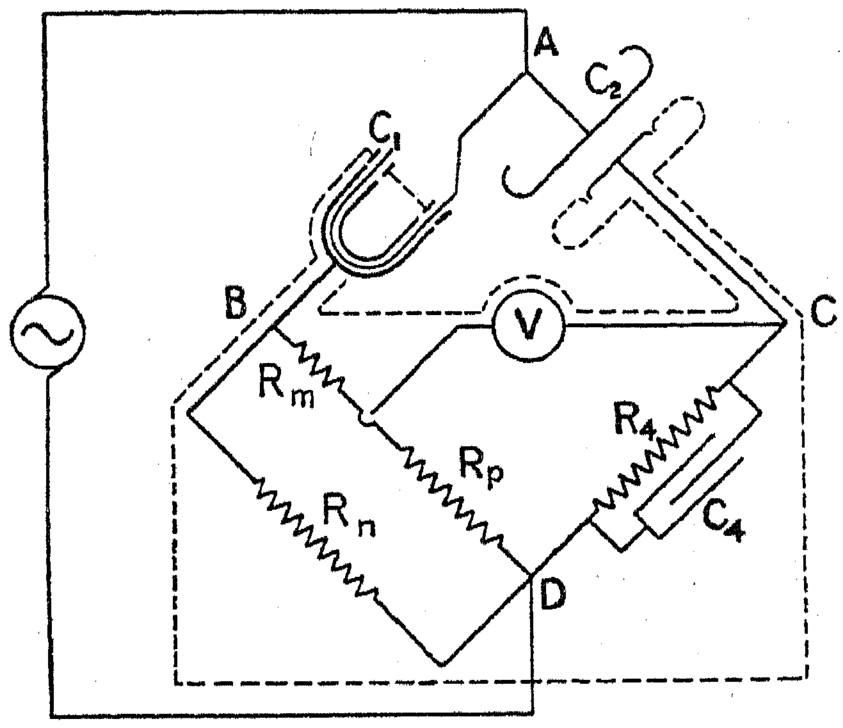

FIG. 2.—Schering-bridge circuit with supplementary resistances.

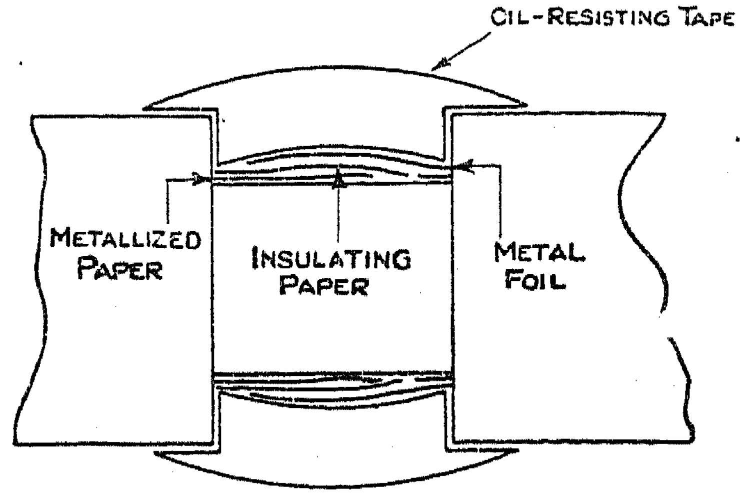

FIG. 3.—Method of preparing guard ring.

For measurements of the highest accuracy, the portion of the cable to be measured must be completely enclosed within an efficient electrostatic screen. In this connection it must be realized that a 1-in. or $\frac{1}{2}$-in. wire mesh which will effect complete capacitance screening will not, in general, effect complete loss-current screening, especially if the tests are being carried out in the neighbourhood of any high-voltage corona or other discharge. For measurements of high accuracy, therefore, the screen must consist of continuous metal, although in particular cases it may be possible to use wire mesh if it can be demonstrated that the conditions of the experiment are such that no loss current arrives at the measuring electrode.

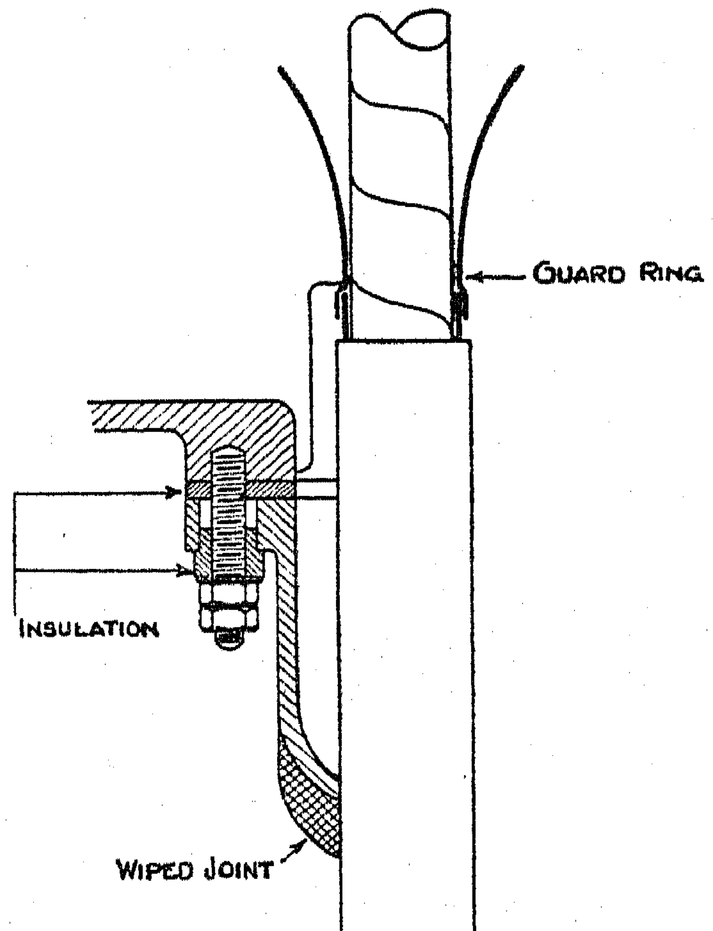

FIG. 4.—End connections when cable is terminated in sealing ends.

The errors due to end effects and to incomplete screening are inversely proportional to the length of the cable under test, and may be negligible on long lengths, e.g. on a drum length of 200 yards. For intermediate lengths a guard ring 1 in. wide, close to the end of the sheath, may be found sufficient. The errors, however, depend on the voltage and on the arrangement of the equipment. The requirements can only be ascertained by experiment.

At high voltages, discharges from the guard rings may interfere with the balance of the bridge. Such discharges should be avoided by some form of stress distributor.

Errors due to inadequate shielding are not necessarily positive, but may make a negative contribution to the apparent power factor.

(v) *Shielding of Transformer for Measurements with Cable-sheath Earthed.*

When the low-voltage end of the bridge is not at earth potential, errors may be introduced by the inter-capacitances and leakages between the primary winding, secondary winding, and tank, of the transformer.

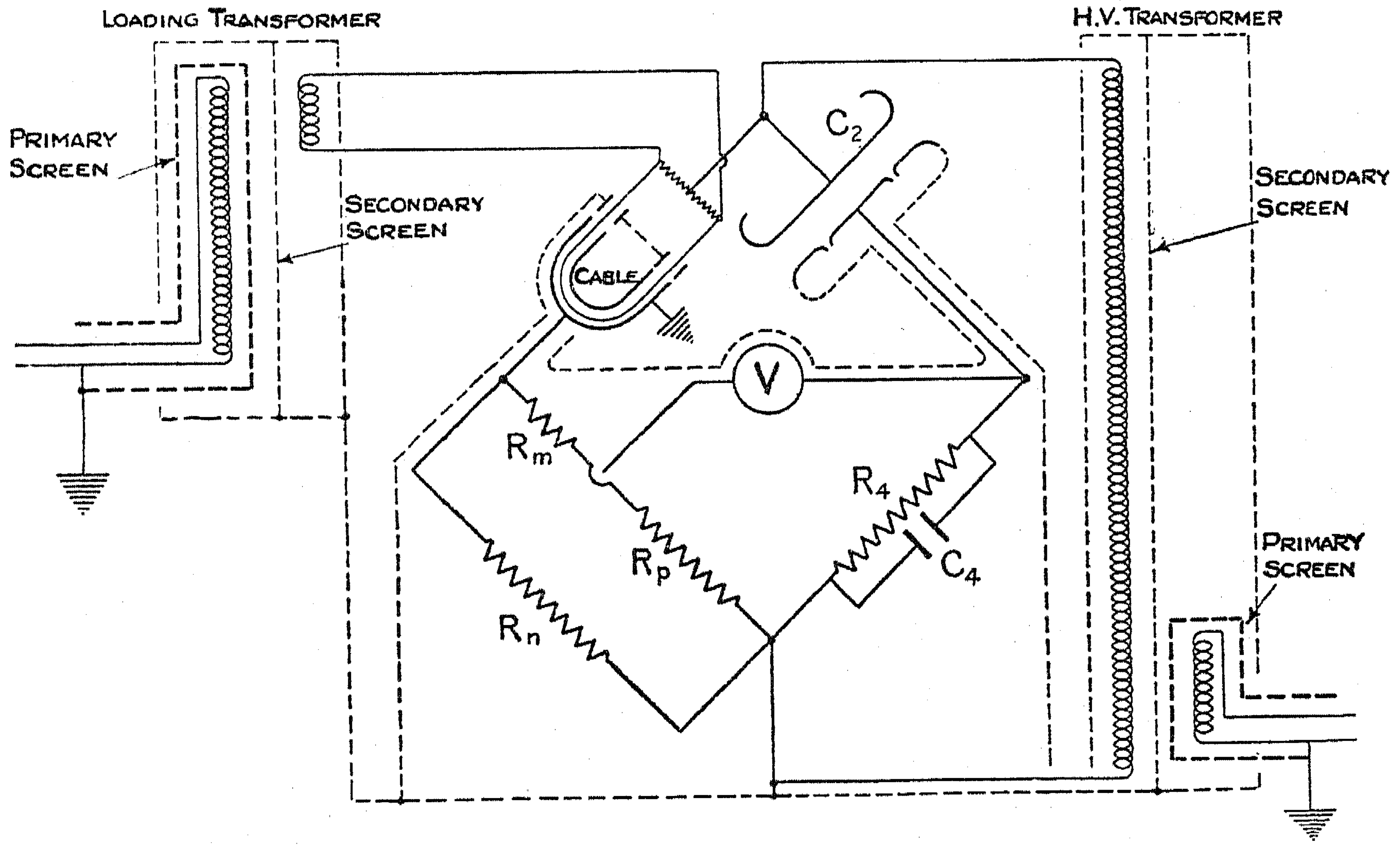

FIG. 5.—Complete connections of Schering-bridge circuit for measurements on a loaded cable.

If the effect of the primary winding is appreciable it is probable that reversing the primary supply will change the apparent power factor measured, unless the supply is symmetrical about earth. The effect can only be eliminated by an earthed screen surrounding the primary winding.

The dielectric losses between the secondary winding and the tank (and screen) are considerable, and may vary with the transformer load. They can be eliminated from the bridge measurements by connecting the insulated tank, and a screen surrounding the secondary winding, to the low-voltage end of the bridge. For accurate measurements, therefore, a doubly-screened transformer is desirable, the primary-winding screen being earthed and the secondary-winding screen and tank being connected to the low-voltage end of the bridge.

Any other transformers connected to the circuit, such as loading transformers and potential transformers, must be shielded in a similar manner. For measurements on loaded cables the bridge connection, if found necessary, may be made to the mid-point of a resistance connected across the ends of the core of the cable, to exclude the voltage of the loading transformer from the bridge.

A diagram showing the complete connections is given in Fig. 5.

(vi) *Evaluation of Power Factor and Capacitance.*

The capacitance is given by

$$\frac{C_2R_4}{R_3} \quad \text{or} \quad \frac{C_2R_4(R_m + R_n + R_p)}{R_nR_p}$$

The power factor is given by the product $R_4C_4\omega$ subject to the following corrections:—

(*a*) *Correction for capacitance C_4' across R_4.**—Capacitances may be introduced across R_4. For example, connecting all shields to the low-voltage end of the bridge introduces the capacitance between the low-voltage and guard plates of the standard condenser, the capacitance of the shielded lead from the standard condenser, and the capacitance of a galvanometer lead across R_4. The first two may be appreciable.

Such capacitances must be allowed for by adding their value to the reading of C_4.

(*b*) *Correction for capacitance C_3 or C_n across R_3 or R_n.**—The capacitances across R_3 or R_n (Figs. 1 or 2) must be noted. For example, connecting all shields to the low-

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* The complete formula for the power factor, allowing for all possible stray capacitances, is

$$\omega R_4\left[C_4 + C_4' - \frac{R_m}{R}\left(C_2 + C_g + \frac{C_2}{C_1}C_g\right)\right] - \omega C_n\frac{R_n(R_m + R_n)}{R_m + R_n + R_p} - \omega C_p\frac{R_p(R_n + R_m)}{R_m + R_n + R_p} + \omega C_m\frac{R_m^2}{R_m + R_n + R_p}$$

C_p and C_m respectively being the capacitances across R_p and R_m, and C_g being the capacitance between points B and C. In general, the capacitance corrections given in (*a*), (*b*), and (*c*), will be sufficient.

voltage end of the bridge introduces the capacitance of the shielded lead to the cable across R_3 or R_n, besides that of a galvanometer lead. If the low-voltage end of the bridge be earthed, the capacitance of the cable-sheath to earth is added. If the cable-sheath be earthed and the insulated transformer tank be connected to the low-voltage end of the bridge, the earth capacitance of the tank must be allowed for. If a doubly-screened transformer be used, as described in (v), then the capacitance of the first screen to the second screen and the tank is added.

If the total capacitance be C_3 or C_n, a correction of amount $R_3C_3\omega$ or

$$\frac{R_n(R_m + R_p)}{R_m + R_n + R_p}C_n\omega$$

must be subtracted from the apparent power factor.

(*c*) *Correction for capacitance C_g between points B and C of the bridge* (*Fig.* 2).[*]—When the cable-sheath is earthed and the shields are also earthed, a capacitance C_g is introduced between points B and C. If the form of the bridge shown in Fig. 2 be used, a correction of magnitude $(R_m/R_p)R_4C_g\omega$ must be subtracted from the apparent power factor.

(*d*) *Correction for phase angles of resistances.*—When cables of large capacitance are being tested the resistance may be of the order of an ohm, and it is likely to be inductive to an appreciable extent, the effect of which is to make the apparent power factor too low. The phase angles of the resistances R_n, R_4, R_m, and R_p, should also be known, though they should be inappreciable if the resistances are of the convenient order of 100 ohms. If the leading phase angles be denoted by θ_n, θ_4, θ_m, and θ_p respectively, then the correction required is

$$\theta_4 + \frac{R_m}{R_m + R_p}(\theta_m - \theta_p) - \theta_n$$

(*e*) *Correction for length of cable.*—With very long lengths of cable, an error is introduced due to the resistance and inductance of the cable. The error may be of the order of 0·001 for a length of 5 miles. If R is the total resistance of the line (go and return), C the total capacitance, and L the total inductance, then the correction

$$1 - \frac{\arctan\sqrt{(jRC\omega - LC\omega^2)}}{\sqrt{(jRC\omega - LC\omega^2)}}$$

must be subtracted from the apparent power factor.[†]

For lengths up to 10 miles, the approximation $\frac{1}{3}RC\omega$ is sufficient.

(*f*) *Correction for transformer and similar losses with the cable-sheath earthed.*—A measurement of the losses must be taken with the cable disconnected, and if necessary this measurement must be subtracted vectorially from the measurement with the cable connected. If, in Fig. 6, the length OA and the angle AOB represent the capacitance and the dielectric-loss angle respectively measured with the cable connected, and the length AC and the angle CEB represent the measurements obtained with the cable disconnected, then the length OC and the angle COD represent the capacitance and dielectric-loss angle respectively of the cable alone.

For accurate work, doubly-screened transformers should be used as described in (v). The zero measurement then only deals with the stray-capacitance currents from the high-voltage conductor, and if this be of large diameter the losses may be found to be negligible.[*]

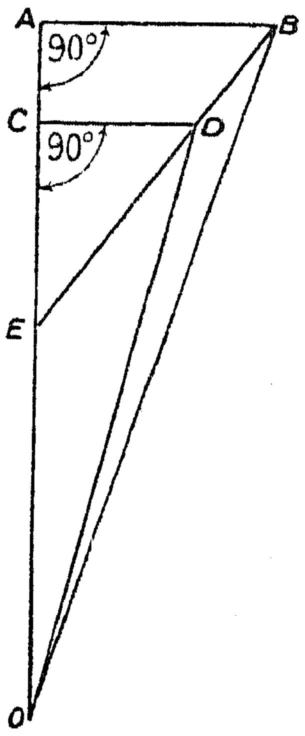

FIG. 6.—Method of correcting for transformer losses.

(vii) *Elimination of Capacitance Corrections.*

(*a*) With the circuit of Fig. 1, the capacitance corrections referred to in (vi)(*a*) and (vi)(*b*) may be eliminated by adjusting the voltage of the shielding system to that of the vibration galvanometer, by means of the subsidiary circuit indicated in Fig. 7. Adjustment is made by successive approximation with the switch in positions A and B alternately.

With the circuit shown in Fig. 2, the shields of the standard condenser and of all leads connected to point C of the bridge may be adjusted to the same voltage as C in a similar manner. The capacitance corrections referred to in (vi)(*a*) and (vi)(*b*) are then eliminated, but, in the case of the cable-sheath being earthed, another error is introduced; it may be allowed for by adding to C_n the capacitance to earth of the shields referred to.

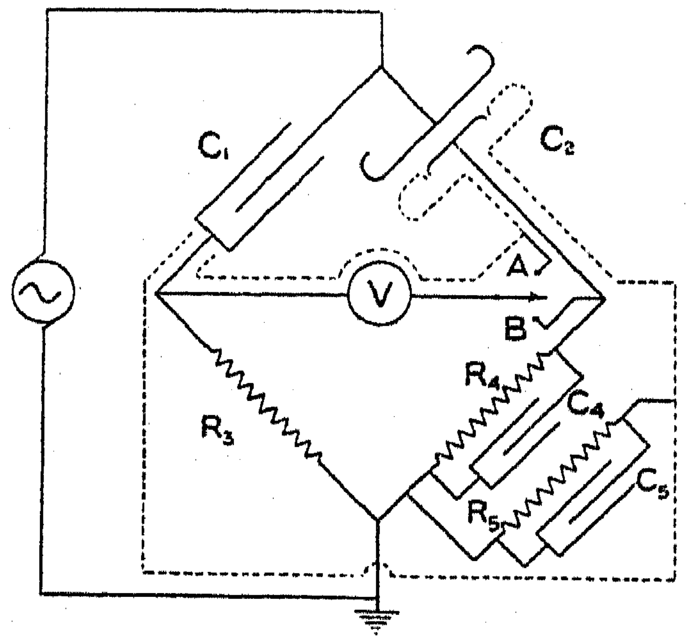

FIG. 7.—Method of eliminating capacitance corrections.

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[*] See footnote on page 847.

[†] The formula is derived from the solution of the cable equation (see L. G. BRAZIER: *Journal I.E.E.*, 1931, vol. 69, p. 757).

[*] The time-constants of the resistances R_n, R_4, R_m, and R_p, may be measured by a low-voltage audio-frequency method, and the phase angles calculated for the test frequency.

The capacitances C_4', C_3, or C_n and C_g, must be measured or calculated for each set-up.

(*b*) Another method of eliminating the capacitance corrections is to take two measurements with different values of R_4 (changing R_4, R_n, R_m, and R_p in the same ratio) and extrapolate to zero resistance. The range of readings required to ensure a given degree of accuracy can be deduced from the slope of the graph obtained.

APPENDIX I.

DESIGN OF AIR CONDENSER.

The principles of design of a loss-free air condenser are illustrated in Figs. 8 and 9. These indicate sections of cylindrical condensers, which are preferable to the plate form, as they have a fixed capacitance and afford more efficient shielding with a given amount of material. In Fig. 8 the high-voltage electrode is the external conductor mounted on insulators, while in Fig. 9 it is the inner conductor suspended from a bushing. In each case the electrode connected to the measuring circuit is the central part of the low-voltage electrode. It is shielded by guard electrodes, which should extend beyond it a distance at least as great as the separation between the high- and low-voltage electrodes, to protect the measuring circuit from extraneous fields. The guard system should entirely surround the low-voltage electrode, including the terminal to which connection is made. The guard system operates at or near earth potential. It should be adequately insulated for testing purposes. All connections, including those to the guard electrodes, should be of low resistance.

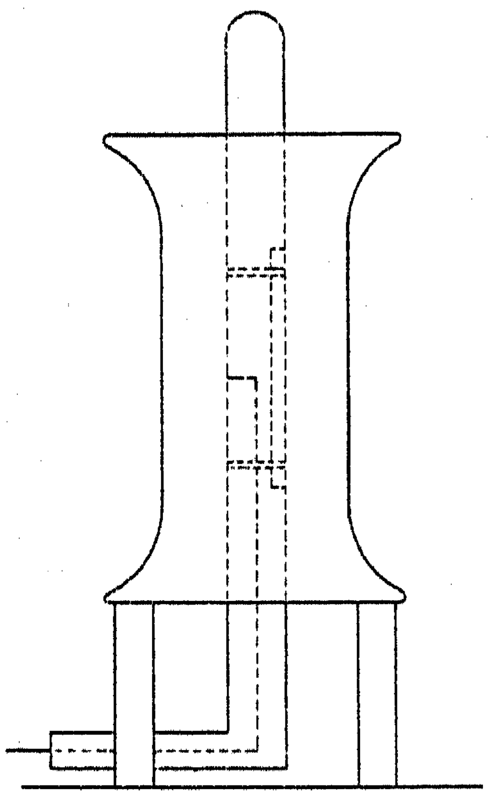

FIG. 8.—Standard air condenser with external high-voltage electrode.

The surface of the electrodes should be clean, smooth, and, preferably, polished. The internal diameter of the outer conductor should not be greater than 2·5 times the external diameter of the inner conductor, to prevent ionization occurring before breakdown.

Referring to Fig. 9, the electric field of the whole system is rendered definite by surrounding it with an earthed metallic screen, for which netting may be used. If sheet metal be used, protection is provided against deposit from a dirty atmosphere on the electrodes, which, when damp, might introduce loss in the standard condenser.

APPENDIX II.

SUBSIDIARY METHODS OF MEASURING POWER FACTOR.

A suitable wattmeter may be a convenient instrument for carrying out measurements of power factor, provided that the results obtained agree with those given by a Schering bridge.

Electrostatic-wattmeter Methods.

A high-voltage electrostatic wattmeter has been used, but such an instrument is generally inconvenient and insensitive. The use of a low-voltage electrostatic wattmeter with 100–1 000 volts on the needle requires some device for the supply of a known fraction of the main voltage for its excitation. The supply may be derived from (*a*) a suitable fraction of the secondary winding of the supply transformer, (*b*) a tertiary winding of the supply transformer, (*c*) the separate potential transformer, or (*d*) a potential-dividing resistor or capacitor. Any of these methods is liable to give rise to serious phase displacement between the derived and the supply voltage, which, when the power transformer is used to provide the measuring voltage, will depend on the excitation and load on the transformer as well as on the frequency.

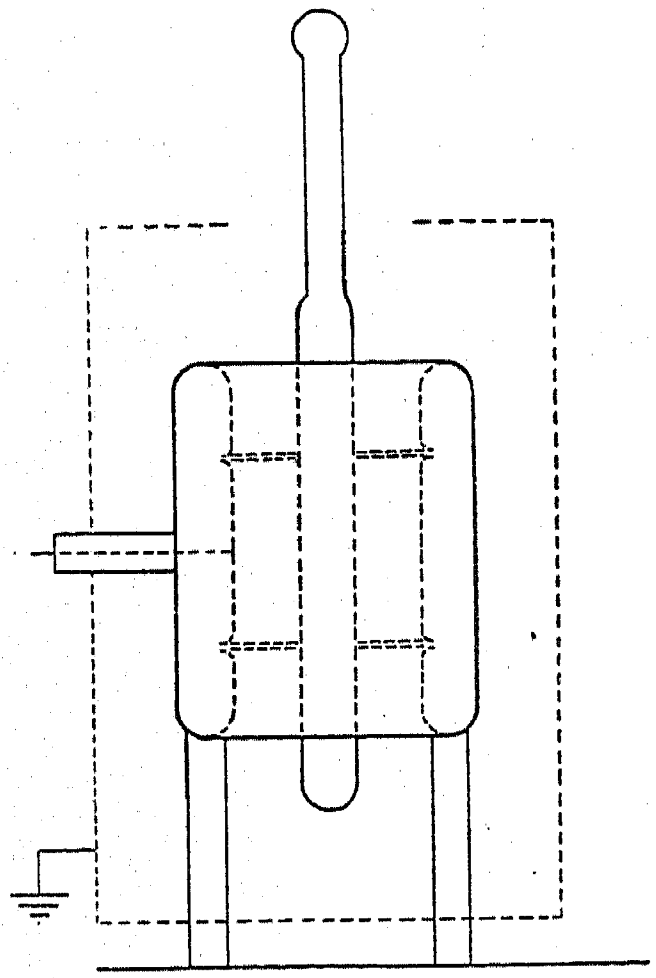

FIG. 9.—Standard air condenser with internal high-voltage electrode.

If a potential-dividing resistor is used, errors due to its self and distributed capacitance are introduced which may be serious. For any given arrangement of a suitable resistor the phase angle will be independent of the voltage, provided there is no leakage or corona as the voltage increases.

Measurements by the electrostatic-wattmeter method should be made with at least two values of the resistance in the current circuit, and the power corresponding to zero value of this resistance should be determined by extrapolation. The well-known error due to the resistance in the current circuit when the needle is not maintained at half the supply voltage, must be allowed for.

Dynamometer-wattmeter Methods.

The dynamometer-wattmeter method may be used either (*a*) to measure the power absorbed in the dielectric, involving measurements of current and voltage to obtain a value of the power factor; or (*b*) to measure the power factor direct by a " compensating " method not requiring a knowledge of the voltage, current, or power. In any case, a current is required for the voltage circuit of the wattmeter, accurately in phase with the supply voltage, or, if it is not in phase, the displacement must be accurately known. Such a current may be derived from circuits of the supply transformer or from a potential transformer or from a resistor, as in the electrostatic-wattmeter method. The fact that an appreciable current is required may render the use of such methods as deriving the current from a tapping on the secondary winding more liable to error than when the electrostatic-wattmeter method is used in a similar manner.

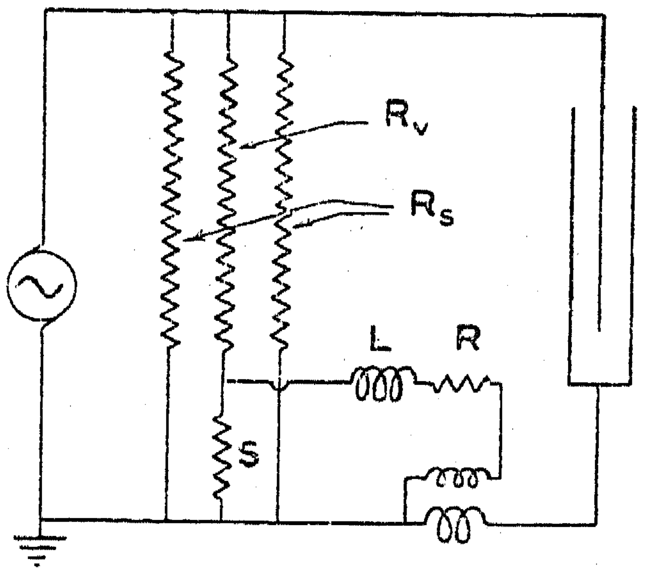

FIG. 10.—Dynamometer wattmeter compensated with self-inductance.

The compensation method may also be used, as shown in Figs. 10 and 11. The indication of a sensitive wattmeter type of instrument is reduced to zero by variation of the self-inductance L in Fig. 10, and by variation of the condenser C in Fig. 11. A resistance R is added to the voltage coil of the wattmeter, partly to reduce the effect of variation of the copper winding with change of temperature, and partly to give the condition that L and C have suitable values. R and S may conveniently be of the order of between 100 and 1 000 ohms.

The power factor is given by $L\omega/(R + S)$ in the case of Fig. 10, and by $RC\omega$ in the case of Fig. 11. Simple numerical values can be chosen for $\omega/(R + S)$ and for $R\omega$, as in the case of the Schering bridge. The value of the power factor so obtained is practically independent of the value of the main resistor R_v in the voltage circuit. Under high-voltage conditions this resistance, R_v, will be very large compared with the resistance of the instrumental part of the circuit, which will have a negligible influence on the phase angle in R_v. The resistance R_v need not be definite, and running water may be used, which greatly simplifies the design of a resistor of small or zero phase-angle. The shielding of a water resistor so as to achieve a very small phase angle between voltage and current in it, can be effected by a similar flow of current in a number of circuits, R_s, concentric with the resistor in the measuring circuit. By adjustment of the relative lengths of the water circuits a condition of zero phase-displacement between the current and voltage in R_v can be obtained.

Very considerable accuracy of construction is required, however, to predict the phase angles of high-voltage resistors; and the values obtained by methods making use of them should be compared, under the conditions of use, with the values obtained by the Schering-bridge method using an air condenser. Errors due to self-inductance and mutual inductance of the wattmeter windings and their capacitance effects can all be included in such comparisons. A length of cable can be used as a reference object.

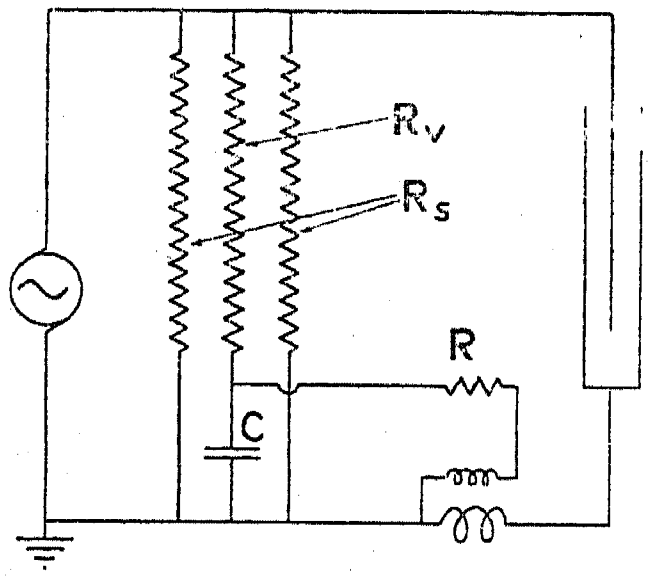

FIG. 11.—Dynamometer wattmeter compensated with capacitance.

The wattmeter and resistor should be shielded from extraneous electric fields. An earth-connected netting will suffice for this purpose. If there is a synchronous disturbing magnetic field present, it can be detected by reversing the connections to both circuits of the wattmeter.

APPENDIX III.

EFFECT OF WAVE-FORM.

The value indicated for the power factor of a cable may vary with alteration of wave-form to an extent depending upon the method, of measurement. The Schering-bridge method may be expected to be the least, and the compensated wattmeter method the most, affected by wave-form alteration.

It has been found when carrying out measurements on a cable that changing the shape from a sinusoidal to a triangular wave does not appreciably affect the Schering-bridge or direct wattmeter methods, while the compensated wattmeter method indicates a lower value of the power factor by about 15 per cent.

THE HISTORY AND DEVELOPMENT OF THE INTEGRATING ELECTRICITY METER.

By A. E. MOORE, M.Sc.Tech., Member.

(*Lecture delivered before the* METER AND INSTRUMENT SECTION *3rd May,* 1935. *A display of historical apparatus, arranged with the co-operation of Mr. R. W. Paul, was on view* ***in the Common*** *Room.*)

In 1880, companies were authorized to sell electrical energy and this necessitated some means of measuring it. There was no reliable meter available although a patent for an electricity meter had been taken out by Pulvermacher in 1868 and a few other patents were taken out between then and 1878 (time meters). But there was no meter industry until very much later and, in general, the company which supplied the electricity made and supplied the meter and all the other gear required for the supply. The interests of the consumers, therefore, appeared to require some consideration and in 1885 Prof. J. A. Fleming read a paper before the Society of Telegraph Engineers "On the Necessity for a National Standardizing Laboratory for Electrical Instruments." Some few years later the Board of Trade set up a laboratory in Whitehall and Major Cardew was appointed the first Electrical Adviser to the Board of Trade. He was succeeded by Mr. A. P. Trotter. Similar laboratories were afterwards set up at Berlin, Paris, and Washington, U.S.A. It became the function of the Board of Trade Laboratory to examine meters for the purpose of approving them, or the type, as being suitable for the measurement of what was called the "quantity contained in the supply." A meter examined and "approved" was sealed and kept at the laboratory as the official sample. Meters made afterwards in accordance with the sample were usually labelled as "approved by the Board of Trade." Many of the early devices which had been patented as electricity meters would certainly not have received the approval of the Board of Trade for their use.

In the exhibit which Mr. Paul has arranged you will find some examples of early meters which have actually been used, and I dare say that those of you who are familiar only with the modern product will regard some of them as just scientific toys. But if you consider the state of our knowledge of electricity at that time you may be able to realize that they were, then, very worthy efforts. It is not easy, even if it were desirable, to compare the ancient with the modern. Young engineers and experimenters to-day have at their command instruments and meters which would have been inconceivable to the engineers of 1880 to 1890. Every year brings forth some new conceptions, some new devices, and it may well be that 20 or 30 years hence, perhaps sooner, some of the meters of to-day may be looked upon by the engineers of that generation as being as fantastic as those of yesterday appear to us to be to-day.

With the adoption of alternating current as the national supply the interest in d.c. meters, particularly of the electrolytic type, has somewhat abated, but it is by no means certain that direct current will not return to favour. Consider what a stir would be created if some means were found of storing electricity in a manner similar to that of storing gas or water, or if a solution were effected of the problem of the efficient generation of electricity directly from the burning of fuel. Either of these discoveries, it seems to me, would affect the position with reference to alternating current and the meter industry.

In former times the question of electricity meters, and of measuring instruments generally, seems to have been considered as of secondary importance to electrical engineers. The idea that the study of measuring instruments could be of any importance by way of assisting in the progress of the construction of machines does not seem to have been appreciated. Measuring instruments and testing were looked upon as a necessary, or perhaps often enough as an unnecessary expense, and tardy recognition was accorded them. I can very well remember how difficult it was to get any but a very few students to take an interest in electrical instruments: they were content to take them for granted. But to-day that is changed and in the generation and supply of electricity a place has been found for the meter engineer. Often in the past, and perhaps to a limited extent at present, the engineer in charge of a station, often a mechanical or civil engineer, was required to do practically everything, including the testing (if any) and installation of the meters. Generally they did not like meters. In about 1915 I visited a small station supplying a small village. The station had some interesting features which, however, do not concern us at the moment. But I noticed that the installations in the cottages consisted of, perhaps, two or three 40-watt, 200-volt lamps; a total load current of about 0·6 ampere. The meters in each of the cottages were of the electrolytic type and were rated for a full-load current of 10 amperes. On leaving the station I said to the engineer, "Tell me, why did you install 10-ampere meters in these cottages when the maximum load is not more than about half an ampere." He said, "Well, I found that I could get a 10-ampere meter for the same price as a 2-ampere meter."

Looking backwards it is often difficult to realize that some defects in apparatus, whether meters or machines, were not easily foreseen and avoided. For example, it is difficult now to understand how anyone constructing a dynamo in which electromotive forces and currents are set up in the copper (metal) windings would fail to realize that they would also be set up in the iron core on which the windings were placed. Yet some early dynamos had solid armature cores and they got hot. The makers did not know why they got hot, so they stopped the machines from time to time to let them cool down, or else bored holes in the cores and circulated water through them to keep them cool. One might give many similar instances, and we should do well to keep this in mind and remember that early meters, like early machines, were developed by experiment rather than by design.

The electric lighting of the early 'eighties was, in the main, by arc lamps, and an early method of charging for the electricity was simply to charge so much per week per lamp installed. This method had many objections to it then, just as it would have to-day, and a later method corresponding to the 2-part tariff was adopted. Charges were made on the basis of so much per week per lamp installed plus so much per carbon consumed in the lamp. The arc lamp itself thus became the measuring instrument and, in consequence, may be considered as one of the earliest types of electricity meter. I believe this method of charging was due to Arthur Wright and one might therefore include a thermal meter among his meter inventions.

When I started to consider the various forms of electricity meters, in preparation for this lecture, I found myself in some difficulty as to which part of the history and development would be most interesting. For example, there was the consideration of the earliest forms of meters, and again of the most modern types of metering equipments, to mention only two, and one could very easily devote the whole time to either. It was suggested to me, however, that some descriptions of the earliest forms would be of very considerable interest. In the busy and progressive life of to-day one has little time to study the relics of the past, however interesting they may be, and consequently they get forgotten; it is useful sometimes to pause and go back. So I propose to include some descriptions, in brief detail, of the earliest meters.

In my younger days electricity was defined as "a subtle invisible fluid known only by its phenomena." Although we think we know something more about it to-day that definition is still not a bad one. Electricity is not a tangible material and we can only measure it by measuring one or other of its effects. There has been no recent discovery of a really new effect of electricity and hence present-day meters do not differ in principles from those of yesterday. The development of meters has been a matter of devising means of improving the design and construction so as to get more accurate and reliable results. Improvements have been made possible not only by our better knowledge of the electromagnetic, electrodynamic and other effects of electricity, but also by the discovery and production of more suitable materials and methods of manufacture.

Many of the early devices suggested and patented as electricity meters for quantity measurement are very ingenious and clever, and their non-existence in practical use to-day is not due to lack of ingenuity. Perhaps, if anything, they show too much of it. The modern meter, on the other hand, in its normal form appears as a marvel of simplicity, but this is often because its complexity is not visible. A piece of variable-permeability steel does not look particularly different from a piece of ordinary steel.

One of the first patents, if not the first, was taken out by Pulvermacher in 1868 for an electrolytic meter in which the gases liberated pushed a liquid up a tube. Some "time" meters were invented between then and 1878, and in later patents, by others, arrangements were made for the liberated gases to be passed through and measured by a gas meter.

In 1878 Lane Fox invented a meter in which the flow of air from a source at constant pressure was regulated and measured by means of a gas meter.

Many other similar devices have been patented and they go to show, I think, that some difficulty was experienced in getting enough power in the meter to drive its own registering mechanism satisfactorily without expending an excessive amount of power in the meter itself. Or it may have been that to many of the inventors the idea of self-registration had yet to be conceived.

Of the different types of meters which have been made and used we have:—

Electrolytic meters.
Thermal meters.
Clock meters.
Motor meters.

These different types were not developed consecutively but contemporaneously; but in order to preserve continuity of thought I have considered it best to deal generally with the development of each type separately. For many reasons the motor type in its various forms is now the most important type.

ELECTROLYTIC METERS.

The inventions of electrolytic meters in the early days of d.c. supply were most prolific and a large number of patents were taken out in respect of them between 1868 and 1906. The meters are, of course, based on Faraday's laws of electrolysis.

The earliest electrolytic meter to be used commercially was that of Edison in 1884, in which zinc electrodes in a solution of zinc sulphate were used. A lamp was put into and out of circuit by means of a bimetal strip to prevent the freezing of the electrolyte. The registration of the meter was determined by an inspector taking out the electrodes at periodic intervals and weighing them. The meter was of the shunted type and in the later forms included what was called a "slow" voltameter. Two tappings were taken from the shunt to two separate voltameters, which registered at relatively different rates so that one formed a check on the other.

Edison had previously patented other electrolytic meters and had also patented (No. 1783/81) the use of a copper resistance in the circuit of the voltameter to compensate for the variation in the resistance of the electrolyte with variations of temperature.

The figure shows an electrolytic meter arranged to be self-registering. Two voltameters are arranged with the electrodes in the form of a balance. The passage of the current disturbs the balance, causing a reversal of the current and hence, by means of a ratchet device.

driving the registering mechanism. You will note that this device is attributed to Edison, 1881. But it is of interest to note that the device was patented three years earlier (No. 4672/78) by J. T. Sprague, father of the present director of Messrs Chamberlain and Hookham. Edison's patent in 1881 was for a gas or water voltameter in which the gases evolved raised a container driving the registering mechanism as it rose. On reaching the top a circuit was closed so that the contained gases were exploded, causing the container to fall again. The idea of explosive meters does not seem to have worried at all the meter inventors of those days. I heard of one form which was tried out in the early part of this century with disastrous results to the meter.

A patent for an ingenious but probably useless device was taken out by Handford in 1882. A voltameter with zinc electrodes had a zinc cylinder geared to the register and placed between the electrodes. As zinc is deposited on one side of the cylinder and taken off the other the equilibrium is upset and the cylinder slowly revolves.

The only types of electrolytic meters which were used to any extent in later times were those of Bastian, Wright, Schattner, Mordey-Fricker, and Holden. They have all been improved from time to time and I understand that some of them are in considerable use at the present time.

The Bastian meter is a very simple meter of the total-current type. The electrolyte was originally sulphuric acid and the electrodes platinum. Later these were changed to caustic soda solution and nickel respectively. The amount of electrolyte decomposed is arranged to give the measurement, and the meter is re-filled with water when required to be re-set. The total voltage-drop is about 3 volts.

The Wright (or Reason) meter is of the shunted type in which a metal (mercury) is deposited and is self-registering. The whole is hermetically sealed in glass and is re-set, when required, by inverting the container. The total drop is about 1 volt.

The Schattner is a shunted, metal (copper) deposition type, but is not self-registering. It is necessary to "weigh" the anode when taking a reading, but the weighing mechanism is self-contained and calibrated in units.

The Long–Schattner meter is a modified form of Schattner type arranged as a prepayment meter. When the circuit is broken at the mercury cup, current is put through a resistance coil which dims the lights, but the meter continues to register. Any loss to the consumer due to "light" coins is compensated when the discs of standard weight are substituted for the coins removed on collection.

The Mordey-Fricker prepayment meter consists of a strip of consumable electrode (copper) which can be fed into the electrolyte by specified amounts when the correct coin is inserted. The circuit is broken when the part of the electrode dipping into the electrolyte is dissolved away.

Two electrolytic meters by Holden formed the subject of a paper before this Institution in 1905. They were both of the water- or gas-voltameter type, but were quite different from each other in action. The first was similar to the Bastian but was arranged to register on a circular dial. The other was of the shunted type and was so designed and constructed that gas was absorbed at one electrode as fast as it was generated at the other, so that the meter could be hermetically sealed and there was practically no e.m.f. of polarization—an essential condition to accuracy in a shunted type of meter. This last type has been further developed and manufactured in Germany by the Siemens-Schuckert Co.

Electrolytic meters are essentially ampere-hour meters, but if of the shunted type one meter can be arranged to register the total quantity on a 3-wire system of supply. Under suitable conditions they may also be used on a.c. supply by using a rectifier, though they are, of course, not independent of wave-shape. The use of an electrolytic meter for alternating current was patented by Anders and Kottgen in 1891, being in the form of a polarized armature working in conjunction with two separate voltameters. The current was thus not rectified but passed in the right direction alternately through two separate voltameters. A chemical rectifier for the purpose was patented by Wright and Reason in 1900, and the Reason meter is used for alternating current with a copper-oxide rectifier at the present time.

The electrolytic meters have often been severely criticized, but much might also be said in their favour.

THERMAL METERS.

Various types of thermal meters have been invented, but I propose to refer to two only.

The first is the "windmill" meter of Prof. Forbes which was awarded the medal of the Franklin Institute in 1888. It is suitable for both direct and alternating current.

The second meter is the Thomson "rocking beam" meter which was patented in this country in 1884. In this meter two bulbs, connected by a tube containing liquid, are arranged as a balance and heated alternately. The liquid is driven alternately in opposite directions, upsetting the balance and operating the register. It was built before his well-known dynamometer meter. Another patent was taken out in this country by Lorrain in 1888 in which several bulbs were arranged at an angle so as to get continuous rotation.

CLOCK METERS.

Numerous meters have been devised in which a clock in some form has been used merely to perform the integration. Many of them show a considerable amount of inventive genius, but, in general, they could never be looked upon as satisfactory meters. For a satisfactory meter integration must be continuous, not intermittent. The meters consist, generally, of an ammeter or a wattmeter movement the moving part of which is periodically and alternately free and clamped. When free the moving part is displaced from zero by a length or an angle which is proportional to the current or the power at that time. The movement is then clamped, for instance between milled-edged wheels in train with the registering dials, and forced back to the zero mark by means of the clock mechanism. This causes a turning of the wheels which is proportional to the displacement of the movement, viz. to the current or the power. The movement is then freed again and takes up a new position corresponding to the load existing at that time, is re-clamped, and the process is repeated. In many of them the period for which the movement is clamped is considerable—about 20 to 30 seconds—and the load, therefore, has time to change very considerably without any corresponding change in the indication. This may be a source of considerable error and makes the meters quite unsuitable for variable loads. Generally the clock must operate continuously whether there be load on the meter or not, and it must keep accurate time.

[The lecturer here gave brief descriptions of the Frager watt-hour meter (1889–90), the Kelvin ampere-hour meter, the Stanley, Parsons, and Murday ampere-hour meter (1896), and the Raps (Siemens and Halske) ampere-hour and watt-hour meter (1889).]

A meter similar in description to the third to which I have just referred was patented by Hookham in 1887. Such meters are obviously unsuited for any but quite steady loads, the Siemens being the least objectionable from this point of view on account of its short period. Reasonable accuracy at light loads would seem to be almost impossible of attainment. I remember seeing a number of the Siemens meters, of the watt-hour type, on a switchboard many years ago.

The second type of clock meters is due, originally, to Ayrton and Perry (1881), and a meter was originally patented by them in 1882 and is on view in the exhibit. In this type the rate of gain—or loss—by a special clock over standard time is made to be proportional to the current or power to be integrated.

[The lecturer here gave a short description of the meter.]

The meter appears to have been re-invented by Aron in 1884 and was later developed by the Aron Meter Co. A similar type of meter was invented and patented by Oulton and Edmondson in 1888–9.

In the early Aron meters two clocks, one giving standard time and the other affected electrically, were included in one case. Later (1887) the two clocks were interconnected through differential gearing so that the registration was effected by the difference in rates of the two clocks. In still later meters short pendulums were used, the meters being electrically wound and self-starting. The short pendulums were compensated for lack of synchronism by reversing the clockwork every 10 minutes, the current in the pendulum coils being reversed simultaneously. The meters can be arranged for a.c. or d.c. work, and for multi-wire and multi-phase loads, being of the true dynamometer type. Portable meters have balanced pendulums and are spring-controlled instead of gravity-controlled. Aron combined the two pendulums so as to use the meter as a 2-element meter for 3-phase measurements. For accuracy it is essential that the forces due to the currents be small compared with the controlling forces, and that the natural frequency of the pendulums remain constant. This meter is capable of a high degree of accuracy and was for many years considered to be one of the most accurate meters made. To-day, however, for alternating current it is practically superseded by the induction meter made by the same firm.

MOTOR METERS.

Motor meters form by far the largest class of meters in use to-day and, so far as manufacture is concerned, they have practically superseded all other types.

From what has been said you will see that it would not be altogether incorrect to speak of electrolytic motor meters and thermal motor meters; but the term motor meter is assigned to those operating on the electrodynamic action of the current, though not necessarily of the dynamometer type.

Edison's patent for an electrolytic meter in 1881 (the explosive one) also covered a motor meter with liquid brake, the armature being connected in shunt to the field which was in series with the main. The motor meter does not appear to have appealed to Edison.

Ayrton and Perry in 1882, under the same patent as their clock meter, included a motor meter with or without soft-iron core and using a liquid brake.

In the same year a patent was also taken out by A. and T. Gray for a motor meter of the Barlow's wheel type with a permanent-magnet field, the motor driving a drum containing liquid and baffle plates.

Then in 1883 followed the dynamometer motor of Siemens and the mercury motor of Ferranti.

From 1883 numerous patents were taken out for motor meters and we get into the company of other pioneers in the evolution of the electricity meter, viz. Hookham, Wright, Ferraris, Shallenberger, Elihu Thomson, and others.

MERCURY MOTOR METERS.

The mercury motor meters are of two general types. The early Ferranti, one of the first motor meters, is based on the mercury motor of Davy (1823), while that of Hookham is a motor of the Faraday disc type, the mercury being used solely for the purpose of conveying current to the rotating element.

Ferranti experimented in 1883 with a form of mercury motor in which a magnet was not used, nor was there any iron in the model. In his lecture before the Royal Scottish Society of Arts, in January 1895, Ferranti explained that he worked out the theory entirely on the phenomena of the attraction and repulsion of parallel and cross currents. The forces obtained were very small and iron was afterwards used to increase them. The meter is a series motor and was developed by Ferranti in a.c. and d.c. forms. The brake action is due to the mercury rotating against a projecting fan, and a shunt coil was used for the purpose of starting the meter. With the square law the torque obviously falls off rapidly with the lower loads. In the a.c. form laminated iron was used. The meter was afterwards successfully developed for direct current, a solid central core of iron being used. Later, a permanent magnet was used to assist the low-load registration, and to prevent the magnet having too much effect a soft-iron sleeve was slipped over it so as to form a keeper. I believe that cases have been known where the meter ran backwards on light loads after a failure of the supply.

In this type of meter liquid friction was used as the brake, and to prevent the ill-effects of surface tension it is essential in all mercury motor meters that the mercury be in a chamber which is as nearly as possible closed. The driving torque is proportional to the square of the current and the brake torque to the square of the speed. Hence the speed is proportional to the current, but the mean speed is proportional to the r.m.s. value of the current on a varying load. This would lead to incorrect results on a varying d.c. load with constant voltage. At the time these meters were in use, however, it is unlikely that rapidly varying loads would be prevalent.

Ferranti explains that when he used the open mercury bath he was disappointed to find that it required 20 amperes to start the mercury rotating; but this current was eventually reduced to 0·3 ampere after enclosing the mercury as completely as possible. The meter was made for currents up to 600 amperes, all the current going through the mercury, and the starting current of all models was 0·2–0·3 ampere, representing about 1/2 000th part of the full-load current in the case of the 600-ampere meter.

Chamberlain and Hookham started in 1885 to construct, under the patents of Dr. John Hopkinson, a watt-hour meter with a friction brake. Then Hookham invented a meter of the watt-hour type in 1887–8, connections being made to the fine-wire armature by means of mercury cups. The armature was supported on anti-friction rollers.

After this came the disc motor, again using mercury cups and disc commutators, a permanent magnet, and an eddy-current brake. The armature or rotor (weighing 3¾ lb.) in this case was not immersed in the mercury. The rotor was made with copper strip windings mounted on, but insulated from, a copper disc, the ends of the windings being connected to disc-form commutators dipping in the mercury cups. Current was caused to flow radially in the strip windings between the poles of a battery of permanent magnets enclosed in a brass tube, the mercury taking the place of the brushes for the commutators. The copper disc acted as a brake disc, and a magnet shunt was provided for adjustment. This meter, I think, can hardly be called a mercury motor meter since the mercury is not intended to rotate; but the mercury motor which followed it worked on the same principle.

It seems to me that the early Ferranti (Davy) meter is the only type which, strictly speaking, ought to be called a mercury motor, since it is the only type in which the mercury forms the rotor proper. In the Hookham type, and all its followers, the rotor proper is a copper disc or bell, and the mercury is merely the means of conveying the current to it.

Hookham then invented another type of mercury motor meter in which the copper disc rotor is entirely immersed in the mercury, and this meter is the prototype of all the mercury motor meters as we know them to-day. Two discs were used, a slotted disc for the rotor and an unslotted one for the brake. The meter known as the 1897 pattern is an improved form, and this meter—which is still being made to-day—and the Ferranti one previously described held for many years the field in this country for d.c. ampere-hour meters of the motor type.

In 1900–1, a new mercury motor meter, the Ferranti–Hamilton, with eddy-current brake was brought out by Ferranti, Ltd., and the earlier friction brake type was discontinued. Meters of this general type are now made by a number of different firms. A rather interesting feature, showing the trend of modern design, is the smallness of some of them, due, in no small measure, to the cobalt-steel magnet with its high coercivity.

A certain amount of mercury friction, increasing as the square of the speed, is inevitable. This is compensated by a coil carrying the meter current and having the effect of decreasing the brake torque or increasing the driving torque. With very low-speed meters compensation for the mercury friction has been found to be hardly necessary.

Mercury motor meters of the watt-hour type were first made by Chamberlain and Hookham and are now made by several firms. The magnetic field required in this case has to be proportional to the voltage, and an iron-cored coil is necessary. The iron causes a certain amount of trouble due to hysteresis with varying voltage such as that obtaining on a traction load. The meters are of the 2-disc type. The hysteresis has been compensated for in one make by imposing a demagnetizing m.m.f. on the voltage-coil iron by means of a small cobalt-steel magnet.

A feature of the mercury motor meter is that it is possible to utilize the mercury to " float " the rotor and reduce the weight on the bottom bearing, or, alternatively, to impose the " weight " on the top bearing.

There is admittedly a difficulty in producing a watt-hour meter for direct current comparable in performance with the modern induction meter for alternating current. I can remember suggestions being made about 1916 to convert the direct current into alternating current so that it could be measured by induction meters. Some of the suggestions made to me were quite as grotesque as some of those for the earliest meters. Many were based on the fallacy that d.c. motor meters could be produced without commutators, brushes, or moving contacts.

Commutator Meters.

These are of two classes, the watt-hour type and the ampere-hour type. The watt-hour type are usually referred to as the Thomson type but are, perhaps, better referred to as the dynamometer type. Edison in 1881, Ayrton and Perry in 1882, and Siemens in 1883, patented dynamometer types with liquid brakes, and the Siemens meter was so constructed that the case could be filled with oil. The brake torque of most of the early meters of this type was produced by fluid friction (liquid or air), and where the square-law driving torque obtains a square-law brake torque is essential. Ayrton and Perry are credited with the conception of using the eddy-current brake for the control, and also in 1884 Deprez showed that for the watt-hour meter of Siemens the eddy-current brake is essential as the control if driving and controlling torques are to be proportional. Then Hummel conceived the idea of compensating for the friction by means of a starting coil. (Compare method adopted by Ferranti in his early meter.)

From these conceptions of Edison, Ayrton and Perry, Siemens, and Hummel, came the watt-hour meter of

Elihu Thomson in 1888, which, improved from time to time by various designers and manufacturers, is the type mostly used for the measurement of electrical energy on d.c. loads at the present time.

In some earlier types a saturated electromagnet was used as the brake magnet, the winding being in series with the voltage coil. This winding took the place of the non-inductive resistance which is now used. The meters, if suitably compensated, can be made to be accurate on alternating current at different power factors and to be practically independent of the frequency of the supply. Thomson meters were in general use in this country for alternating current until the satisfactory development of induction meters which have now almost entirely superseded them.

There are the troubles which arise from the commutators and brushes and, in the case of large-current meters, from the effects of the currents on the brake magnets. For direct current it is now usual to shunt the meters, but, as the current shunted is comparatively large, care has to be exercised with the connections between the meter and the shunt. If used for alternating current, current transformers would be used, in which case the resistance of leads and contacts in the secondary circuit is of rather less importance.

From time to time modifications have been made to eliminate the defects at the commutator. In the oscillating meter developed simultaneously by Hummel and Lotz and made by the A.E.G., the armature does not rotate but has the current in it reversed after each approximate quarter revolution. Contacts and more complicated mechanisms are required to do this, and other defects are substituted for those of the commutator. The brush gear on modern meters of this type is very different from and much more reliable than that used in the earlier meters.

Friction introduces troublesome defects into motor meters, and in 1900 Evershed invented his frictionless meter. The rotating armature was magnetically suspended so as to reduce the weight on the bottom bearing practically to zero, the brushes were in the form of anti-friction rollers and the register was operated by a relay, thus removing the friction from the meter proper. This meter formed the subject of a paper read before this Institution in 1900. Magnetic suspensions have since been and are now used also by other manufacturers.

The other class of commutator meters is of the ampere-hour type and the meters are based on the principle of the perfect motor. The first meter of this type was patented by O'Keenan in 1898 and is known as the O.K. meter. It is of interest to note that in his discussion on the paper read by Mr. Ratcliff and myself in 1911, Mr. Evershed stated that this meter was originally invented by James Swinburne and re-invented later by O'Keenan.

If we could have a motor without friction and resistance, this type would form a perfect ampere-hour meter for direct current. It has an advantage over the mercury motor for small currents, since in the mercury motor the current cannot be put through the armature more than once. Friction, however, causes the speed to fall rapidly at light loads. The law for the meter is as follows:—

$$n = \frac{Ir}{BN} - \frac{f(r + R)}{B^2N^2}$$

This equation is of the form $y = ax - b$, and results in the percentage error increasing rapidly with the lower loads. It is, of course, possible to compensate for the friction error by using a nigh resistance connected as a permanent small load on the meter, as Ferranti did in his earlier meters. The driving torque on the meter is then in the form represented by the equation $y = ax + b$ and the friction error can thus be cancelled. If this is done, however, a watt-hour meter might just as well be used, though there is more danger of sparking at the brushes with the watt-hour type. On the other hand the lower voltage of the ampere-hour meter is a disadvantage so far as variable resistance at the commutator is concerned.

Other methods are adopted to mitigate the defects of friction. Stronger magnets will improve the load curve and reduce the speed. Automatically moving the brushes over the commutator surface is said to reduce the friction error. (O'Keenan's patent, 1907.) Another method is by using a specially designed commutator and arranging for the brushes to be moved with the load so as to make contact at different parts, the neutral axis of the field being also shifted, so that the driving torque per ampere at the lighter loads is greater than the torque per ampere at the higher loads. Many of these meters are made with disc-form armatures, the windings being fixed inside an aluminium disc which acts as a brake and reduces the speed.

INDUCTION METERS.

The last class of motor meters, the induction type for alternating current only, has, perhaps, been developed more than any other type. The adoption of large multi-phase systems for the generation and transmission of electric power supply calls for a.c. meters of the highest precision and at the present time there is no other type of meter which is more suitable than the induction type. In the earliest forms the torque was very small and considerable errors were introduced with changes in the voltage or power factor of the supply, and also with the load itself.

Induction meters start with one very great advantage over other types in that it is not necessary to provide connections for the purpose of delivering current to the rotating element. This at once eliminates brushes, commutators, ligaments and contacts, and their attendant defects.

The method of producing a rotating magnetic field by means of 2-phase current is due to Ferraris, who carried out his experiments in 1885. He did not publish his discovery immediately, however, and Borel and Paccaud in France, and Shallenberger in America, invented induction meters in 1888 and, it is sometimes asserted, before Ferraris published his invention which was, however, for the purpose of producing an electric meter. From 1888 various forms of induction meter were invented, among the inventors being Shallenberger, Wright, Ferranti, Blathy, and Scheefer. The first inventions of Shallenberger, Wright, and Ferranti, were ampere-hour meters, and of Blathy a watt-hour meter. The Shallenberger was the first induction meter, and perhaps the first a.c. meter of practical utility, and was manufactured by the Westinghouse Co. and used for a considerable time. The Blathy meter is generally considered to be the first watt-hour meter of the induction type and the first induction meter to be used successfully in Europe.

The accuracy of the induction watt-hour meter on loads at other than approximately unity power factor depends upon the existence in the meter of the correct phase relation between the voltage and current fluxes. In most cases the true relation is not established without some form of correction. Theoretically, the voltage flux should be in quadrature with the voltage, and hence the device for bringing this about is often called the "quadrature adjustment," but more frequently now, I think, the "power factor corrector." In 1895 Shallenberger solved the problem by means of a secondary winding on the voltage magnet and his method, in various forms, is the one mostly used to-day. Other methods utilizing current-splitting and flux-splitting have also been devised and are in use. It is interesting to note that the Shallenberger method can be and has been applied to the dynamometer type to correct for the large phase error introduced by the rather high inductance of the armatures. In the induction meter the correction can be made for only one frequency at a time. This is partly due to the fact that the disc itself of the rotor may be considered as a quadrature band and, as I showed in a paper read before this Section in 1930, it is possible, for any particular frequency, to choose a disc of suitable thickness so that no additional correction is necessary. A very large assortment of shapes for the driving system is used.

The torque in early induction meters, as in most early meters, was small, and the load curves for the meters were far from straight lines. A great improvement has been made possible by better design and the use of better materials.

A great deal of litigation took place from 1900 to 1904 in connection with the Tesla patents relative to the split-phase motor, and these patents were held to cover the elements of induction meters. The result of this was that the development of the induction meter was very much retarded until the expiry of the patents in 1910.

You will see that in the last part of the last and the early part of the present century a large variety of types of electricity meters was available, and in 1911 Mr. H. A. Ratcliff and I read before this Institution a paper on electricity meters in which we outlined what we then considered to be the merits and demerits of the types in use at that time. The paper lead to a somewhat controversial discussion, both at the meetings at which it was read and also in the electrical Press. These various types have now been reduced to motor meters of the mercury, commutator, and induction types.

RECENT DEVELOPMENTS.

I propose to turn now to the developments of recent times. Perhaps we might say that the more important developments have been in connection with induction meters. The adoption of the national grid, resulting in the general supply and use of alternating current, has led to a vast increase in the demand for a.c. meters, and for the purpose the induction meter stands pre-eminent. The improvements in induction meters lie mainly in two directions, (1) the extension of the load curve, and (2) the reduction—in some cases the almost entire elimination—of the electromagnetic interaction between the elements of a multi-element meter.

With reference to the load curve, in the early meters, as has already been mentioned, the curve was not a straight line even for a comparatively short range of the load, but in the modern meter a nearly straight line is possible from a very small load to upwards of several times full load. This has been brought about partly by an increase in the voltage flux and the use of more powerful brake magnets. Increasing the voltage and brake-magnet fluxes will make the fluxes of fixed magnitude large in comparison with the variable current flux. Generally speaking this results in a decreased speed as well as a flatter curve. The question of whether it is desirable to reduce the speed of meters to a very low value is a debatable one. So far as the effect on pivot and jewel wear is concerned, with lower speeds we have less wear by rotation but probably more by vibration. An increased voltage flux may cause increased hammering, side thrust, and noise, and this may offset the decreased rotational wear. The possibility of hammering and side thrust depends upon the form and symmetry of the driving magnet. For example, if the voltage magnet is not symmetrical on both sides of the disc the disc will be repelled from the stronger or nearer magnet pole.

In the case of multi-element meters it is essential, generally, that each element be entirely unaffected by any other element if the meter is to be accurate under all conditions of loading. There are three forms of interaction which may take place between the elements: (1) an interchange of the driving fluxes; (2) an interchange or combination of the eddy currents in the disc when two or more elements are arranged around one disc; and (3) the increase in the brake torque due to the current flux of an additional element. The interchange of working fluxes has been largely eliminated by providing a complete magnetic circuit of iron around the driving element of the meter. This construction tends to the use of a disc of smaller diameter and consequent lower peripheral speed. Eddy-current interference can be eliminated by the use of separate discs for each driving element, or by using a disc having a non-conducting centre part of glass or bakelite so as to permit of more than one element being placed around the disc without the eddy-current due to one element straying to the fluxes of another element. The third form of interference is likely to be very small, probably negligibly small in a modern straight-line meter.

There is a general tendency to reduce the geometric dimensions and the weights of meters and to house them in cases of "shock proof" materials. Provided that the reduction in size does not result in a reduction in good performance this is all to the good. The meter occupies less space and is more readily housed in consumers' premises, and the appearance of the meter is enhanced so that there is less desire on the part of the consumer to have it housed in a dark and damp cellar.

Cellars, however, are rarely provided in the modern house and one wonders what the consumer would say if a meter like some of those early ones, weighing about half a hundredweight and occupying the space of a small meat safe, were installed. In this connection, in his contribution to the discussion of the 1911 paper already referred to, Col. Edgcumbe suggested that integrating meters might receive more considerate treatment if they were housed in more presentable cases. A cartoon relative to this was published at the time, showing meters in various forms of period furnishings such as Chippendale, Sheraton, and Queen Anne, etc.

Much improvement has also been effected in the manufacture of brake magnets. The brake magnet controls the speed of the meter and is therefore of fundamental importance. Before the War, magnets were obtained from abroad in considerable quantities; but when the War commenced supplies were stopped and, as was the case with many other commodities, they had to be produced at home. Meter manufacturers now generally make their own magnets and the excellence of the product indicates what an effective stimulus necessity is. The restriction in the use of tungsten during the War was also responsible for the discovery of the cobalt-steel magnet with its high coercivity of about 250, and in some cases 600, c.g.s. units. In meters of the straight-through dynamometer type for very large currents the powerful magnetic fields produced by these currents was always likely to, and often did, affect the stability of the brake magnets. The use of shunts and current transformers has reduced this defect to smaller dimensions. In order to preserve the stability of the magnets some makers of meters now "age" them after instead of before the complete assembly of the meters, by putting the whole meter in a rotating magnetic field and increasing the field strength until the desired demagnetization has been effected.

Varying friction is detrimental to the accuracy of meters and its effect is greatest when applied to the faster running parts. The footstep or bottom bearing usually consists of a hard steel pivot and a natural or synthetic sapphire jewel. Outside the meter industry it is rarely realized what immense stresses are imposed on this member of the meter. In some of the Thomson type the stress is as high as 200 tons per sq. in., and in modern induction meters it is about 15 tons per sq. in. With such great stresses anything which will minimize the ill effects of shocks is desirable, and spring-supported jewels, for which patents were taken out in 1898, are now universally used in integrating meters. Much work has been done more recently in improving the footstep bearings. It is now general to have an oiled bearing, but efforts are being made, with some measure of success, to produce a satisfactory dry bearing. Ordinarily, the great stresses at the pivot points cause rusting with an unoiled pivot.

Research work goes on continuously in the works of the manufacturers, and no effort is spared to produce a meter which will give accurate and reliable service for very long periods. Pivots and jewels are subjected to a critical and searching examination for faults. Completed meters are subjected to very severe tests, and any which fail to pass are rejected. They are made to withstand the rough handling which they often get. It was very different in the case of the early meters.

Another important accessory in the development of the modern meter is the small self-starting synchronous motor. It has enabled improvements to be made in the mechanisms for operating demand indicators and has made it possible for time switches to be made more reliable and their times synchronized. Demand indicators are now all of the Merz–Price type in so far as they are worked directly from the meter in conjunction with a time switch.

Further development in modern metering equipments is in the addition of components to make the meter provide information in addition to the mere kilowatt-hours used. Since electricity cannot be stored in the same manner as, say, gas and water, special consideration and tariffs have to be given to the various types of consumer. This often leads to its being necessary to measure quantities other than kilowatt-hours, e.g. kilovolt-ampere-hours, reactive kilovolt-ampere-hours, maximum demands, power factors, etc., and the ingenious but complex metering equipments designed for the purpose are somewhat disconcerting to the non-technical consumer. In 1891 Aron patented the use of 2-element meters for measuring the energy on 3-phase loads, and multi-element meters of other manufacture could be produced only under licence from the Aron company until the expiry of the patent. Now, meters of 2, 3, and 4, elements are constructed for various purposes, but there is no simple meter for the measurement of kilovolt-ampere-hours, and a single form of meter does not at the moment seem possible of construction or design. We can make meters to give us $\int VI \cos \phi dt$ and also $\int VI \sin \phi dt$, but the simple addition of these two quantities does not give us $\int VI dt$.

In the exhibit there is an example of a metering device by the Westinghouse Co. in which a sphere is used to add the two quantities in the right proportion so that the registration is proportional to $\sqrt{[V^2I^2\cos^2\phi + V^2I^2\sin^2\phi]}$, that is to VI. A similar device, called a Ball-Gear meter, has also recently been developed by Siemens-Schuckert, using a ground glass sphere instead of an aluminium one. The Trivector meter of Landis and Gyr, and the KVA meter of Hill-Shotter by the Aron Meter Co., are also to be seen in the exhibit.

When we study these metering equipments it seems as if we are going back to those days when clockwork mechanisms were used to perform functions which the meter itself was unable to do. Perhaps, in the future, all the operations performed by these complicated mechanisms will be readily and easily performed by a single, simple meter. Who knows?

And now, what about the future? Time will not permit me to deal with this as I might like to do. In the paper by Ratcliff and myself we stated that meters could not be considered as fully satisfactory until they registered within 1 per cent of accuracy under all reasonable conditions of service. Well, induction meters are now produced which are rather better than that and it might be supposed that that is the end. But it is evidently dangerous to put limits to progress. In a paper by Silvanus Thompson in 1913 he suggested that an optimum value of 80 for the coercivity of magnet steel might be expected or hoped for: yet to-day we have the cobalt-steel magnet with a coercivity perhaps undreamed of at that time. Indeed, such a coerciviyt might then have been considered fantastic: and who would have thought of alloys like mumetal with its permeability of something near 100 000? For the present, the modern induction meter appears to do most of all that is required of it and to do it very well. The designers and manufacturers have produced a meter which is reliable and which measures kWh accurately under practical conditions of supply. But the induction meter is not perfect; and while we know practically all there is to know about the dynamometer type and can, therefore, judge of its limitations so far as possible accuracy is concerned, there are some things about induction meters which are not yet fully understood. We do not know, therefore, whether the limits of accuracy have been reached, and that is a sufficient reason for the meter designer and research worker to go on; and go on they will: they cannot help themselves. Supply engineers will continue to state their requirements, and, however fantastic those requirements may appear to be, the meter industry will, in part or in full, sooner or later fulfil them.

And now I must confess to a feeling of having failed to do justice to those wonderful pioneers of the early days of the electricity meter. Those early meters were not designed as we understand the term design to-day. One had an idea and then experimented with it: the result was sometimes delight, but more often it was disappointment. I think that by an examination of and some quiet meditation over some of those early efforts one can discover that there is something romantic surrounding " The History and Development of the Integrating Electricity Meter."

I must not conclude without a reference to the exhibit. It was a happy thought on the part of the Committee to ask Mr. Paul to add to the lecture by arranging an exhibit of meters illustrating the progress in meter development. I am sure that the thanks of all of us are due to Mr. Paul for having arranged such an interesting exhibit.

REPORT OF THE COUNCIL FOR THE YEAR 1934–1935, PRESENTED AT THE ANNUAL GENERAL MEETING OF THE 16TH MAY, 1935.

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REPORT.

The Council, at the Sixty-Third Annual General Meeting of The Institution of Electrical Engineers, present to the members their Report for the year 1934–35, covering approximately the period from the 1st April, 1934, to the 31st March, 1935.

The Council desire once more to express the most cordial thanks of the Institution to the many members who further its work so ably and efficiently by the considerable amount of time which they ungrudgingly give to the carrying out of the Institution's numerous activities. Such assistance and co-operation help most materially in enhancing its prestige and status in the eyes of the authorities and of the public.

(1) MEMBERSHIP OF THE INSTITUTION.

The changes in the membership since the 1st April, 1934, are shown in a table included in Appendix A.

The following table shows the net growth of membership for the last 10 years:—

Year	Membership	Increase
1926	12 142	+ 399
1927	12 647	+ 505
1928	13 043	+ 396
1929	13 561	+ 518
1930	14 200	+ 639
1931	14 670	+ 470
1932	14 884	+ 214
1933	15 149	+ 265
1934	15 619	+ 470
1935	16 150	+ 531

(2) HONORARY MEMBER.

The Council have pleasure in recording that, as announced at the Ordinary Meeting on the 24th January, 1935, they have elected The Rt. Hon. Lord Hirst of Witton to be an Honorary Member of the Institution.

(3) FARADAY MEDAL.

The thirteenth award of the Faraday Medal was made by the Council to Frank Baldwin Jewett, Ph.D.

(4) HONOURS AND DISTINCTIONS CONFERRED ON MEMBERS.

Barony.

Hirst, Sir Hugo (Honorary Member).

G.C.B.

Stamp, Sir Josiah, G.B.E., D.Sc., Sc.D., LL.D. (Companion).

C.B.

Kennedy-Purvis, Charles Edward, Rear-Admiral, R.N. (Member).

McNaughton, Andrew G. L., Major-Gen., C.M.G., D.S.O. (Associate Member).

C.B.E.

Hawkins, Charles C., M.A. (Member).

O.B.E.

Caparn, Eric Thomas, M.C. (Associate Member).
Mayne, Arthur James (Member).
Weaver, Richard Albert (Member).
Wheeler, Roland (Member).

Croix d'Officier de la Légion d'Honneur.

Rowell, Percy Fitz-Patrick (Companion).

(5) DEATHS.

The Council regret to have to record the death of the following 102 members of the Institution during the year:—

Members.

Aulton, F. P.
Birkett, R.
Blake, A. W.
Bond, F. A.
Braithwaite, J. B., Jun.
Bridger, W., B.Sc.(Eng.).
Chattock, A. P., D.Sc., F.R.S.
Clinton, Prof. W. C.
Donoghue, J. E.
Emmott, W.
Everett, E. I.
Ewing, Sir J. A., K.C.B., LL.D., F.R.S.
Fahie, J. J.
Fitzmaurice, J. S.
Fitzpayne, F. A.
Forster, J. P.
Gray, John, B.Sc.
Gray, Prof. J. G.
Hall, J. P.
Harrington, J.
Harris, A. F.
Hopkins, W. B.
Jobson, R. H. T.
McLellan, W.
Marshall, W. H. U.
Milne, F. L.
Mylan, W. F. M.
Percy, H. L.
Petersen, T.
Rice, C. W.
Ruck, Major-Gen. Sir R. M., K.B.E., C.B., C.M.G., R.E.
Russell, C. N.
Schuster, Sir A., K.B.E., LL.D., Ph.D., Sc.D., F.R.S.
Scotson, R. H.
Scott, J., J.P.
Slingo, Sir W.
Sprague, F. J.
Sutton, Sir G., Bart.
Timm, J. M.
Watson, J. S.
Wilson, N. J.
Wingfield, B. R., Ph.D.

Associate Members.

Alabaster, W. H.
Atkinson, J.
Bird, G. W., B.Sc.(Eng.).
Birtwistle, M.
Bowden, E., D.Sc.
Casey, Lieut.-Com. A. D.
Chambers, J. L.
Chaplin, G. R.
Cole, G. F.
Cooper, W. V.
Creasy, L. A.
Davis, C. M.
Davis, F. W.
Deem, J. S. L.
Eddington, A.
Finney, S. H.
Gallop, C. C.
Gowan, S.
Hambly, J.
Harrison, F. O.
Jenkins, H. C.
Jennings, O. C.
Mathieson, T. B.
Maudling, A. W.
Melville, O.
Peck, G. T., B.Sc.
Penning, J. R.
Philip, A., B.Sc.
Rattenbury, G.
Reid, D. G.
Rylands, F. B.
Scarborough, E. A.
Shaw, E. A.
Simpson, W. B.
Smith, William.
Swinburn, B. B.
Telfer, J., B.Sc.
Walder, E. D. L., B.A.
Warrack, J.
Wells, T. F.
Wilkins, E. H.
Woodhouse, C. H. C.

Companion.

Beatty, A. H.

Associates.

Jones, F. W. E.
Langlois, T.
Woodson, J. P.

Graduates.

Fletcher, D. W. R.
Hall, W. S. H.
Keddell, J. A., B.Sc.
Morris, W. I., M.A.
Osborne, C. P.
Raisin, A. H.
Watkins, T. P., B.Sc.(Eng.).

Students.

Adam, S. C.
Butler, H.
Kennedy, T. W.
Orford, G.
Pearce, E. C.
Robinson, J. H.
Smale, D. W.

(6) COUNCIL BALLOT: CANVASSING FOR VOTES.

It is desired to remind members that the Council strongly deprecate organized canvassing, by means of circulars or otherwise, in favour of those nominated for election to the Council.

Consideration will be given at the next revision of the Bye-laws to the submission to the members of a new bye-law which will disqualify nominees in favour of whom organized canvassing has taken place.

(7) EXAMINATIONS.

Graduateship Examinations were held in May and November, 1934, in London, Belfast, Birmingham, Cardiff, Dublin, Glasgow, Loughborough, Manchester, Newcastle-on-Tyne, and Norwich, and also, in November only, in Australia, Bermuda, Ceylon, Egypt, Federated Malay States, India, Malta, New Zealand, South Africa, Zanzibar, and in H.M.S. *Medway*.

In addition, a number of candidates were permitted to fulfil the educational requirements for Associate Membership by the submission of papers or theses in lieu of the Examination.

Mr. J. H. Sprawson was awarded the Page Prize (value £4 4s.) for the thesis submitted by him, his subject being "Experience and Conclusions on the Running of the Cape Town–Simonstown Electrification of the South African Railways."

(8) NATIONAL CERTIFICATES AND DIPLOMAS IN ELECTRICAL ENGINEERING.

England and Wales.—In 1934 the Joint Standing Committee, representing the Board of Education and the Institution, was associated with the final examinations of 184 courses at colleges and schools in England and Wales, approved in connection with the above certificates and diplomas.

The final examinations were held during the summer of 1934, and the number of awards was as follows:—

804	Ordinary Certificates.
353	Higher Certificates.
45	Higher Certificates endorsed.
18	Ordinary Diplomas.
9	Higher Diplomas.

Scotland.—In conjunction with the Scottish Education Department, the Institution was associated with 14 courses in Scotland during the year under review.

The final examinations were held during the summer, and the number of awards was as follows:—

19 Ordinary Certificates.
16 Higher Certificates.
14 Higher Diplomas.

(9) SCHOLARSHIPS.

The following Scholarships have been awarded by the Council during the Session:—

Ferranti Scholarship.
(Annual Value £250; tenable for two years.)
F. C. Williams, M.Sc. (Manchester University).

Duddell Scholarship.
(Annual Value £150; tenable for three years.)
S. I. Hollingworth (Chipping Campden Grammar School).

Silvanus Thompson Scholarship.
(Annual Value £100, plus tuition fees; tenable for two years.)
S. G. Bittles (Messrs. Harland and Wolff, Ltd., Belfast).

Swan Memorial Scholarship.
(Value £120; tenable for one year.)
E. Bradshaw, M.Sc. (Royal Technical College, Glasgow).

David Hughes Scholarship.
(Value £100; tenable for one year.)
W. B. Hutchison (Royal Technical College, Glasgow).

Salomons Scholarships.
(Value £50; tenable for one year.)
R. Bernard (Heriot-Watt College, Edinburgh).
W. McStravick (Heriot-Watt College, Edinburgh).

Paul Scholarship.
(Annual Value £50; tenable for two years.)
No award.

Thorrowgood Scholarship.
(Annual Value £25; tenable for two years.)
K. N. Fordham (London, Midland and Scottish Railway Co.).

War Thanksgiving Education and Research Fund (*No.* 1).

The Council have made grants from the above Fund for research purposes as follows:—

£50 each to
R. R. C. Rankin (Royal Technical College, Glasgow);
H. Walton (King's College, London).

With the exception of the Paul Scholarship, which is awarded in alternate years only, all the above scholarships and grants may be awarded annually.

(10) INSTITUTION BUILDING.

As in former years, the free use of the Institution premises has been granted to a number of kindred societies in connection with their meetings, and 237 such meetings were held during the past year.

Appreciable damage was caused to some of the upper rooms of the building by a fire which occurred on the third floor, in the premises tenanted by the Lighting Service Bureau of The Electric Lamp Manufacturers' Association. The damage was fully covered by insurance.

(11) MEETINGS.

During the past twelve months, 510 meetings were held in London and at the Local Centres by the members, the Council, and the various Committees. A detailed statement is given in Appendix B.

(12) UNAUTHORIZED USE OF MEMBERSHIP INITIALS.

During the past year there have been several cases of the use, by unauthorized persons, of initials or descriptions implying that they were members of the Institution. It has been possible in all cases to ensure the discontinuance of the practice by the persons concerned without the necessity of taking legal action.

(13) COLONEL R. E. B. CROMPTON, C.B.

On the occasion of his attaining the age of ninety on the 31st May, 1935, a number of members and others are presenting to Colonel Crompton an oil painting of himself by George Harcourt, R.A. The Council have gladly accepted a generous offer for the painting to be given to the Institution, and it will in due course be included in the Institution's collection of oil paintings.

(14) COOPERS HILL WAR MEMORIAL PRIZE.

The award of the Coopers Hill War Memorial Prize, which consists of a bronze medal, a parchment certificate, and a money prize of £20, fell this year to the Institution, and the Council selected for the award Mr. A. M. Wright, M.Sc., for his paper on "Electrification of Railways."* Seven papers were submitted for consideration. Only Corporate Members of the Institution under 35 years of age are eligible to compete.

The Prize consists of two awards, one of which is made annually by the Institution of Civil Engineers, and the other triennially in turn by the Institution of Electrical Engineers, the School of Military Engineering, Chatham, and the School of Forestry, Oxford.

(15) PREMIUMS.

The Premiums awarded by the Council for papers read at meetings or accepted for the *Journal* will be announced about the time of the Annual General Meeting.†

(16) LOCAL CENTRES AND SUB-CENTRES.

The attendances and proceedings at the meetings of the Local Centres and Sub-Centres have maintained the high standard of the past.

The President attended functions and meetings at the Centres at Bristol, Glasgow, Leeds, Liverpool, Manchester, and Newcastle-on-Tyne, as well as at the East Midland, Sheffield, and Tees-Side Sub-Centres, and he will be present at a meeting in Dublin to be held in April. He was represented at the Annual Dinner of the South Midland Centre at Birmingham by Mr. R. P. Sloan, C.B.E., Vice-President.

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* See page 826.

† See vol. 76, page 717, and vol. 77, page 147.

At each of the places so far visited by him the President addressed those present and was gratified to note the keenness of the members and their evident appreciation of the opportunities for discussion and intercourse afforded by the meetings, etc.

Full details of the meetings and other activities of the Local Centres and Sub-Centres are contained in the Annual Reports presented each year to the local members.

(17) ACTIVITIES OF OVERSEAS MEMBERS.

The Overseas Activities Committee of the Council are very gratified at the continued increase in the activities of the Institution overseas. During the year two further Local Committees have been set up, one at Calcutta and the other in Ceylon.

In addition to the activities of the Argentine and China Centres, details have been received of social gatherings and of meetings for the reading and discussion of papers. These functions, which are arranged by the various Local Committees, have been held with success in New South Wales, Queensland, South Australia, Victoria, Western Australia, Ceylon, and at Bombay and Calcutta.

In some instances papers already read in London have been read and discussed, while in other cases papers have been written and presented by local members.

The third Annual Conversazione and Reunion of members from overseas, and their ladies, was held in the Institution building on Wednesday, 11th July, 1934. The total attendance was over 130, the arrangements being similar to those made for the two previous functions.

(18) LOCAL HONORARY SECRETARIES ABROAD.

During the Session, the Council appointed Mr. Vivian J. F. Brain as Local Honorary Secretary of the Institution for New South Wales in place of Mr. J. E. Donoghue, who resigned from this office. The Council have learned with regret of Mr. Donoghue's subsequent death.

The Council have also appointed Mr. C. Selwood Plank as Local Honorary Secretary for New Zealand in place of Mr. A. C. Owen, who has resigned from that office.

(19) WIRELESS SECTION.

The interest and activities of the Wireless Section, whose membership is 728, continues to be well maintained. Seven meetings have been held during the past year, at which 6 papers were read. In addition, 5 papers have been published or accepted for publication in the *Journal*. The average attendance at the meetings was 130, as compared with 157 for last session.

A most interesting visit to the British Broadcasting Corporation's long-wave National Broadcasting Station at Droitwich took place on the 26th May, 1934. Excellent arrangements for directing the party over the station were made by the chief engineer, Mr. N. Ashbridge, B.Sc.(Eng.), and his staff. Over 90 members took part, and the success of the visit was most gratifying.

The Committee decided in January last, with the approval of the Council, to include in the programme of activities of the Section, Informal Discussions of a popular character on subjects of wide interest such as broadcasting, transmitters, and receivers. Members of the Section were invited to introduce non-members to the meetings, an innovation which proved most successful as the average attendance at the three meetings held was 363.

(20) METER AND INSTRUMENT SECTION.

Eight meetings of the Meter and Instrument Section have been held during the past year, the average attendance being 99, which compares with 83 during the preceding twelve months. As in previous years, the meetings have included one which has been devoted to an Informal Discussion on various subjects. All the meetings were most successful and the papers read evoked interesting discussions. It should be noted that at several of the meetings the papers were accompanied by demonstrations of apparatus, and the Committee are making a point of encouraging such demonstrations whenever practicable. In addition they are considering the possibility of arranging short demonstrations of apparatus and processes which come within the scope of the Section but which do not necessarily relate to the subject matter of the paper being read on the same evening. Members of the Section who consider that they may have suitable material for demonstrations of this kind should send particulars to the Secretary for consideration by the Committee.

The Summer Visit for 1934 was held on Saturday, 5th May, and over 100 members and ladies took part. The programme included a visit to the Water-Street Depot of the Birmingham Corporation Electricity Department, a drive round Messrs. Cadbury's village at Bournville, and an afternoon excursion through Shakespeare's country.

The Section held its Annual Dinner on the 16th November, 1934, the attendance being 134.

The membership is now 603.

(21) TRANSMISSION SECTION.

The new Transmission Section of the Institution commenced its meetings on the 21st November, 1934, when its first Chairman, Mr. R. Borlase Matthews, delivered his Inaugural Address. This meeting has been followed by monthly evening meetings, at all of which papers of high merit have been read and at which the discussions have been interesting and well sustained. In this connection it should be noted that the following Premiums have been set up for Transmission Section papers:—

The Sebastian de Ferranti Premium (value £20).
An Extra Premium (value £10).

A successful Conversazione and Dance, which was attended by 245 members and guests, was held on Friday, 23rd November, 1934. The function included an exhibition of apparatus, etc., coming within the scope of the Section. In addition, arrangements are also being made for a Summer Visit to take place towards the middle of May, and the Committee hope to be able to arrange similar functions and visits in future years.

It is gratifying to note that members are giving the Section substantial support, the membership having already nearly reached 1 550.

(22) Informal Meetings.

Ten meetings have been held during the year, the average attendance being 94, as against 88 last year.

The Informal Meetings Committee again cordially invite members to write to the Secretary indicating subjects which they wish to suggest for discussion. Offers from members to open discussions will also be welcomed and carefully considered by the Committee.

(23) Students' Sections.

A full programme of meetings, visits to works, and social functions, has been carried out during the session at the nine Students' Sections, viz. at London, Birmingham, Bristol, Glasgow, Leeds, Liverpool, Manchester, Newcastle-on-Tyne, and Sheffield. Full details and accounts have been given from time to time in the *Students' Quarterly Journal.*

The actual membership of the nine Sections is in the aggregate 3 670, which includes some 1 650 Graduates under the age of 28, who are entitled under the Bye-laws to the same privileges as Students.

The "Students' Lectures" were delivered this session by Mr. A. P. M. Fleming, C.B.E., M.Sc., and Mr. Clifford C. Paterson, O.B.E., at the places indicated:—

Lecturer.	*Subject.*	*Place.*
Mr. A. P. M. Fleming, C.B.E., M.Sc.	"Development in the Materials of Construction of Electrical Plant and Apparatus—Magnetic, Insulating, Conducting, Mechanical."	Edinburgh } Scottish Glasgow } Section Leeds Newcastle-on-Tyne Sheffield
Mr. C. C. Paterson, O.B.E.	"Modern Street Lighting."	London Birmingham Bristol Liverpool Manchester

The total attendances at the 10 lectures were approximately 730, compared with 660 for the 10 lectures given last session by other lecturers. Although the lectures were greatly appreciated, it is felt that these figures should be considerably higher, taking into account the total membership of the Sections. Arrangements have been made for Mr. Fleming and Mr. Paterson to be the lecturers again next session, each to give the same lecture at the Sections which he did not visit during the present session. It is hoped that the lectures next session will receive greater support.

In order to secure uniformity of procedure in the functioning of the respective Students' Sections, the separate Rules for each Section which had hitherto been in force were replaced during the session by a uniform set of Rules applicable to all the Sections. The new Rules came into operation on the 1st January, 1935.

The fourth Annual Meeting of the Honorary Secretaries of the Sections was held in London on the 8th February, 1935, when a very useful and interesting discussion took place on points of organization and routine.

In August last a Summer Meeting was organized by the London Students' Section (in conjunction with the National Union of Students), to the Ruhr and Rhine districts of Germany. The party, which numbered 27 and included members from nearly every Students' Section in the provinces, stayed a few days in turn at Cologne, Düsseldorf, Essen, and Dortmund. The programme included visits to the following works:—

Rhine Westphalian Electrical Co. (R.W.E.) at Knapsack and at Herdecke.
Messrs. Deutz Motors at Cologne.
Messrs. Demag at Duisburg.
Messrs. Siemens-Schuckert at Mulheim-Ruhr.
Messrs. Krupp at Essen.
The Gutehoffnungshütte Coal Mines at Oberhausen.
The Hoesch Steel Works near Dortmund.
The Essen-Mulheim Air Port.

A very enjoyable trip was also made to Königswinter by Rhine steamer, and from there the ascent of the Drachenfels was made by rack railway. In addition, local sightseeing tours were arranged by the municipal authorities of every town visited.

The Council desire to express the thanks of the Institution for the hospitable welcome extended by those who entertained the party and gave facilities for visits to works, etc. The Meeting was highly successful and thanks are due to Mr. A. L. Cramb and Mr. F. J. Tompsett (the leader of the party) for their capable handling of the organization of the tour on behalf of the Committee of the Section, and also to the National Union of Students for the valuable assistance rendered by that body.

The *Students' Quarterly Journal,* now in its fifth volume, has had another successful year. There is an increasing competition for the available space, and this is having a beneficial effect on the standard of the articles published. An innovation this year has been the indication of the Section to which the respective authors are attached. The suggestion for this came from one of the Sections, and is indicative of the pride which the Students take in the publication.

Largely as the result of the greater interest caused by the *Journal,* several Sections have for the first time held a meeting at places other than the normal location, notably the Scottish Section at Dundee, the Liverpool Section at Chester, and the North Midland Section at Hull.

It is of interest to record that the London Students' Section are the first holders of the "Young" Trophy, which was presented by Mr. H. T. Young (Vice-President) to be competed for annually, commencing in 1934, at a Sports Contest between the London Students' Section and the Students' and Graduates' Sections of The Institutions of Civil and Mechanical Engineers. The first contest for the Trophy took place in July 1934, and consisted of cricket and tennis matches, a full account of which was given in the September (1934) number of the *Students' Quarterly Journal.* The junior Sections of the three Institutions have already for some years participated in joint meetings in London at which papers of common interest have been read and discussed, and it is felt that the annual contest for the above Trophy will lead to increasingly happy co-operation.

(24) REVIEWS OF PROGRESS.

Continuing the series of reviews of progress in electrical engineering, which have appeared in the *Journal* each year since 1926, reviews on the following subjects have been, or will be, published during 1935:—

Power Stations and their Equipment.
Radio-Telegraphy and Radio-Telephony.
Telegraphy and Telephony.
Transmission and Distribution.

Arrangements have been made for reviews on the following subjects in 1936:—

Electrical Equipment of Automobiles.
Electrical Illumination.
Electrical Plant and Machinery.
Electricity Applied to Ships.
Electro-Physics.
Industrial Applications of Electricity.
Agricultural Applications of Electricity.
Domestic Applications of Electricity.

(25) FARADAY LECTURE.

The Faraday Lecture this session was delivered by Prof. E. W. Marchant, D.Sc., who chose as his subject "Electricity in the Life of To-day." The Lecture was given at Birmingham, Bristol, Liverpool, London, Manchester, and Newcastle-on-Tyne, and will also be given at Dublin and Dundee before the Session closes.

The 6 Lectures so far delivered this session have been attended by a total audience of approximately 4 000, of whom over 3 050 were non-members. The corresponding figures for 9 Lectures delivered in the previous year were 4 689 and 3 614 respectively.

(26) ANNIVERSARY CELEBRATIONS AND CONFERENCES.

During the year under review, the Institution has been represented at Anniversary Celebrations and Conferences, etc., arranged by other bodies as shown in the following table:—

Name of Body.	*Nature and Date of Function.*	*Name of I.E.E. Representative.*
Association of Public Lighting Engineers	Annual Conference, Aberdeen (17–20 September, 1934)	J. A. Bell
Association of Teachers in Technical Institutions	Annual Conference, Middlesbrough (19–22 May, 1934)	R. J. Huntley (then Chairman of the Tees-Side Sub-Centre)
Hoofdcommissie voor de Normalisatie in Nederland	Informal International Conference on the Electrical Equipment of Ships, The Hague (8 June, 1934)	Col. A. P. Pyne, R.A. (T.) (Ret.)
Royal Sanitary Institute	Annual Congress, Bristol (9–14 July, 1934)	A. J. Newman
Société Française des Électriciens	Gaston Planté Centenary Celebrations, Paris (12–14 June, 1934.)	P. V. Hunter, C.B.E. (then President). F. W. Crawter P. F. Rowell (Secretary).
Melbourne Centenary Celebrations	Engineering Conference, Melbourne (4–9 March, 1935.)	J. M. Crawford

(27) SUMMER MEETING.

As forecast in the last Annual Report, arrangements are being made for a Summer Visit to take place in 1935. Belgium has been chosen on this occasion, and a programme is in course of preparation with a view to the visit taking place from the 8th to the 14th September. A programme will be issued to members as soon as the necessary arrangements have been made.

(28) ANNUAL CONVERSAZIONE.

The Annual Conversazione was held on the 21st June, 1934, at the Natural History Museum, London. The total attendance of members and guests was 1 963.

(29) ANNUAL DINNER.

The Annual Dinner was held at Grosvenor House, Park Lane, London, on the 7th February, 1935, when 811 members and guests were present. An account has been published in the *Journal* (vol. 76, p. 448).

(30) LIBRARY.

During the year, 441 books and pamphlets were presented to the Reference Library by members and others and 94 volumes were purchased. The total number of readers for the year was 7 391, of whom 611 were non-members, as against 6 816 and 488 respectively in 1933–34. The Council regret to state that five volumes have been taken by readers from the Reference Library without authority during the past year.

Eighty new volumes were added to the Lending Library and 3 266 books were issued to 1 224 borrowers, the corresponding numbers for the previous year being 3 167 and 1 260 respectively.

351 surplus volumes have been sent to five Local Centres where library facilities are available.

(31) VISITING MEMBERS.

Members are reminded of the reciprocal arrangements for the extension of privileges to visiting members which are in existence between the Institution and the following sister institutions abroad:—

The American Institute of Electrical Engineers.
The Institute of Electrical Engineers of Japan.
The Norsk Elektroteknisk Forening.
The Société Française des Électriciens.
The South African Institute of Electrical Engineers.

These privileges include attendance at meetings, library facilities, and such visits, excursions, etc., as may be in progress. The Secretary will gladly give letters of introduction for the above purpose to any member visiting the countries indicated.

(32) GIFT TO THE INSTITUTION.

The Council express their cordial thanks to the donor of the following gift to the Institution:—

Donor.	*Gift.*
Mrs. P. Christian Dresing.	Case containing specimens of the Woosung - Gutzlaff-Nagasaki - Vladivostok submarine cable, laid in 1883.

(33) SPEAKING PORTRAITS OF EMINENT ELECTRICAL ENGINEERS.

Progress has been made with the collection of short talking-films, to which reference was made in the last Annual Report. Those of whom films have now been made are:—

Sir W. H. Bragg, O.M., K.B.E., M.A., D.Sc., F.R.S.
Col. R. E. B. Crompton, C.B., F.R.S.
Sir J. A. Fleming, M.A., D.Sc., F.R.S.
Sir R. T. Glazebrook, K.C.B., D.Sc., F.R.S.
Prof. A. E. Kennelly, D.Sc
Sir Oliver Lodge, D.Sc., F.R.S.
Mr. W. M. Mordey.
Dr. Elihu Thomson.
Sir J. J. Thomson, O.M., M.A., F.R.S.

The films of Dr. Elihu Thomson and Prof. A. E. Kennelly have been obtained through the kind co-operation of the American Institute of Electrical Engineers. Other films will be added to the collection during the coming year.

Members will be afforded opportunities of seeing the films, which will be exhibited at Institution meetings from time to time.

(34) "SCIENCE ABSTRACTS."

The Physics volume of *Science Abstracts* for 1934 contains 5 269 abstracts, compared with 5 491 in 1933. The Electrical Engineering volume contains 2 992 abstracts, compared with 3 078.

A new feature of the Annual Index of Section "A" (Physics) is the inclusion of a "Supplementary Index of Apparatus and Instruments," in which the papers are classified under the names of the instruments and arranged in alphabetical order.

Science Abstracts, which appears monthly in two sections, namely, Section "A" (Physics) and Section "B" (Electrical Engineering), consists of full abstracts from the leading scientific and technical journals and the proceedings of learned societies of the whole world, and presents in a form convenient for immediate reference a complete and concise record of the progress of physical science and electrical engineering. 1 458 members of the Institution subscribe to *Science Abstracts*, 858 subscribing to both Sections and 600 to Section "B," but the Council earnestly hope that more members will become subscribers to the publication, in view of its exceptional value. It may be obtained, if ordered in advance, by Students of the Institution, as well as by Graduates under the age of 28, at the special rate of 7s. 6d. per annum for both Sections, or 5s. for either the Physics or the Electrical Engineering Section, and by all other members of the Institution at 20s. for both Sections, or 12s. 6d. for either Section alone, the rates charged to the general public being £1 15s. per Section, or £3 for both Sections.

(35) MODEL GENERAL CONDITIONS FOR CONTRACTS.

The set of Model Conditions "A" for the supply of plant and materials and the execution of work connected therewith, for home contracts, last revised in April, 1929, is again being revised, and a new edition will be issued as soon as possible.

The proposed set of Model Conditions "E" for the supply, laying, and erection of electric mains (overhead and underground), for home contracts, is still under consideration.

(36) REGULATIONS FOR THE ELECTRICAL EQUIPMENT OF BUILDINGS.

A revised edition (Tenth) was issued in September, 1934, embodying the amendments which had already been issued in the form of leaflets; at the same time a thorough revision and complete rearrangement were made, important features of which are simplified numeration, division of the Regulations into Sections, and separation of the clauses dealing with "Installation" from those dealing with "Design." There has been a very great demand for copies of the revised Regulations, probably in part due to the recognition of the Regulations by the Electricity Commissioners in the new Electricity Supply Regulations.

The Wiring Regulations Committee have commenced the preparation of the Eleventh Edition. In this connection suggestions for amendment of the Regulations should preferably be made through the medium of a technical or trade body, if possible an Association represented on the Committee.

(37) REGULATIONS FOR THE ELECTRICAL EQUIPMENT OF SHIPS.

The Ship Electrical Equipment Committee are proceeding with the revision of the Second Edition of the above Regulations. In order to expedite the work, they have appointed several Sub-Committees to assist in the revision and in dealing with the numerous matters which arise from time to time in connection with the Regulations.

(38) ELECTRICITY REGULATIONS.

A new Code of Regulations "For Securing the Safety of the Public and for Insuring a Proper and Sufficient Supply of Electrical Energy," issued by the Electricity Commissioners, came into force on the 15th January, 1934. This was based largely upon the recommendations of the Electricity (Supply) Regulations Committee, which were approved by the Council.

(39) COMMITTEE ON ELECTRICAL INTERFERENCE WITH BROADCASTING.

A full Report, covering the work of the Committee to December, 1934, was published in the December, 1934, issue (No. 456) of the *Journal* (vol. 75, p. 801). In Appendix II of that Report, which dealt with the international aspect of the question, it was stated that a group of five experts would meet in Berlin in October, 1934, to proceed with the comparative tests referred to in the Appendix. The experts met on the 3rd December and carried out a series of tests. As a result of these tests a method of measurement was decided upon and it was agreed that tests using this method should be made in the various countries represented on the Special International Committee. These tests are now in progress and the results will be discussed at a further meeting of experts and subsequently by a Plenary Meeting of the Special Committee. A further meeting of the Institution Committee will be held as soon as the results of these tests are available. The Specification referred to in the Annual Report for 1933–34 is now being prepared by the British Standards Institution, and when ready will be submitted to the Electrical Interference Committee for approval before issue as a British Standard Specification.

(40) COMMITTEE ON OVERHEAD LINES.

The Council have approved, and have submitted to the Electricity Commissioners, a Report of the Committee recommending the following alterations to the Overhead Line Regulations El.C. 53 (Revised):—

(1) That as earthing bars cannot be made universally satisfactory Regulation 18 dealing with Road Crossings, etc., should be modified to delete any reference to earthing bars and that certain modified proposals should be substituted.

(2) That Regulation 18 should be modified to require duplicate pin insulators (when used) to be on a line at right angles to the line of the conductors.

(3) That Regulation 14 (2) (*b*) (i), requiring bonding of all metal work on low- and medium-voltage lines where wooden poles are used, should be amplified by requiring the connection of the bond to the neutral conductor.

(41) BENEVOLENT FUND.

The Committee of Management of the Benevolent Fund of the Institution report that on the 31st December, 1934, the total assets of the Fund amounted to £25 711 12s. 6d. of which £23 860 2s. 8d. was on Capital Account, and £1 851 9s. 10d. in respect of unexpended income. The donations and subscriptions to the Fund in 1934 amounted to £2 753 2s. 7d., in which amount are included the proceeds of Golf Competitions organized by the Mersey and North Wales (Liverpool) Centre (£90), the North-Western Centre (£70), the Scottish Centre (£19 15s.), and the North-Eastern Centre (£14 3s.). In addition to the foregoing, the Fund benefited by the surplus of £209 17s. 1d. on the Electrical Engineers' Ball for 1934, and gifts were received from the organizers of similar functions in the provinces (£150 from the South Midland Electrical Engineers' Ball, £40 from the Ball arranged by the North Midland Centre, and £25 from the Ball arranged by the Sheffield Sub-Centre). A gift of £36 was also received from the British Electrical Development Association, being part of the proceeds of a carnival held at Newcastle-on-Tyne. Full details are shown in the Accounts of the Fund for 1934.

The Committee are gratified to report that during the year the Fund benefited by two legacies, viz. £900 from the estate of the late Sir George Sutton, Bart., who for many years was an annual subscriber to the Fund, and £847 13s. 6d. from the estate of the late Mr. John McKenna.

In the course of 1934, grants were made to 50 persons, amounting to a total of £3 051 6s. 9d. During the last few years the annual totals of the grants made have shown a marked increase.

The Council earnestly desire to bring the Fund to the notice of all members of the Institution. At present 30 per cent of the members subscribe to the Fund, and the Council appeal to the remaining members to send donations or promises of annual subscriptions of any amount, which will be gratefully received.

Electrical Engineers' Ball.

The Ball, which was held at Grosvenor House, Park Lane, on Friday, the 8th February, 1935, was most successful, and the Fund benefited by receiving the whole of the surplus of £244. Cordial thanks are due to the General and Executive Committees of the Ball and the stewards for their valuable assistance.

(42) SUMMARY OF ANNUAL ACCOUNTS.

Income and Expenditure.—The surplus on the Revenue Account for the year ended 31st December, 1934, is £8 516 10s. 6d. This amount has been carried to the Balance Sheet, and compares with a surplus of £4 997 16s. 6d. in 1933.

Surplus of Assets over Liabilities.—Taking the investments at cost and the Institution building and lease, the library and furniture, etc., at the values standing in the books after writing off depreciation—

	£	s.	d.
the Assets amount to	210 337	2	0
against Liabilities	8 572	2	11
leaving a surplus of	201 764	19	1
which, in comparison with that of the year 1933, viz.	194 401	18	1
shows an improvement of	£7 363	1	0

The surplus of £201 764 19s. 1d. referred to above is made up as follows:—

Assets

				£	s.	d.
Institution building and lease				73 028	6	10
Investments, cash, etc.				130 089	8	10
Stock of paper, libraries, and furniture ..				7 219	6	4
				£210 337	2	0
Less *Liabilities.*						
Trust Fund Accounts ..	230	8	1			
Sundry Creditors ..	4 940	9	1			
Repairs Suspense Account	3 125	6	1			
Subscriptions received in advance	275	19	8			
				8 572	2	11
				£201 764	19	1

Investments.—The following investment was made during the year:—

	£	s.	d.
£2 500 London Passenger Transport Board 5 % "B" Stock (1965–2023), cost ..	3 017	1	0

During the year an amount of £100 North Metropolitan Power Station 5 per cent Guaranteed Debenture Stock (1957) was drawn for redemption, and was repaid at par.

(43) THE INSTITUTION AND BODIES ON WHICH IT IS REPRESENTED.

Appendix C (page 869) shows in diagrammatic form the organization of the Institution and the bodies on which it is represented.

APPENDIX A.

MEMBERSHIP OF THE INSTITUTION.

The changes in the membership since the 1st April, 1934, are shown in the following table:—

	Hon. Mem.	Mem.	Assoc. Mem.	Com.	Assoc.	Grad.	Stud.	TOTAL.
Totals at 1 April, 1934	15	1 970	6 157	109	1 395	3 244	2 729	15 619
Additions during the year:—								
Elected ..	1	2	143	2	65	320	805	1 338
Reinstated	—	1	11	—	4	3	2	21
Transferred to ..	—	78	243	—	2	430	—	753
Totals ..	1	81	397	2	71	753	807	2 112
Deductions during the year:—								
Deceased ..	—	42	42	1	3	7	7	102
Resigned ..	—	13	49	1	11	56	64	194
Lapsed ..	—	8	72	—	59	77	316	532
Transferred from ..	—	—	78	—	21	211	443	753
Totals ..	—	63	241	2	94	351	830	1 581
Net Increase								531
Totals at 1 April, 1935	16	1 988	6 313	109	1 372	3 646	2 706	16 150

APPENDIX B.

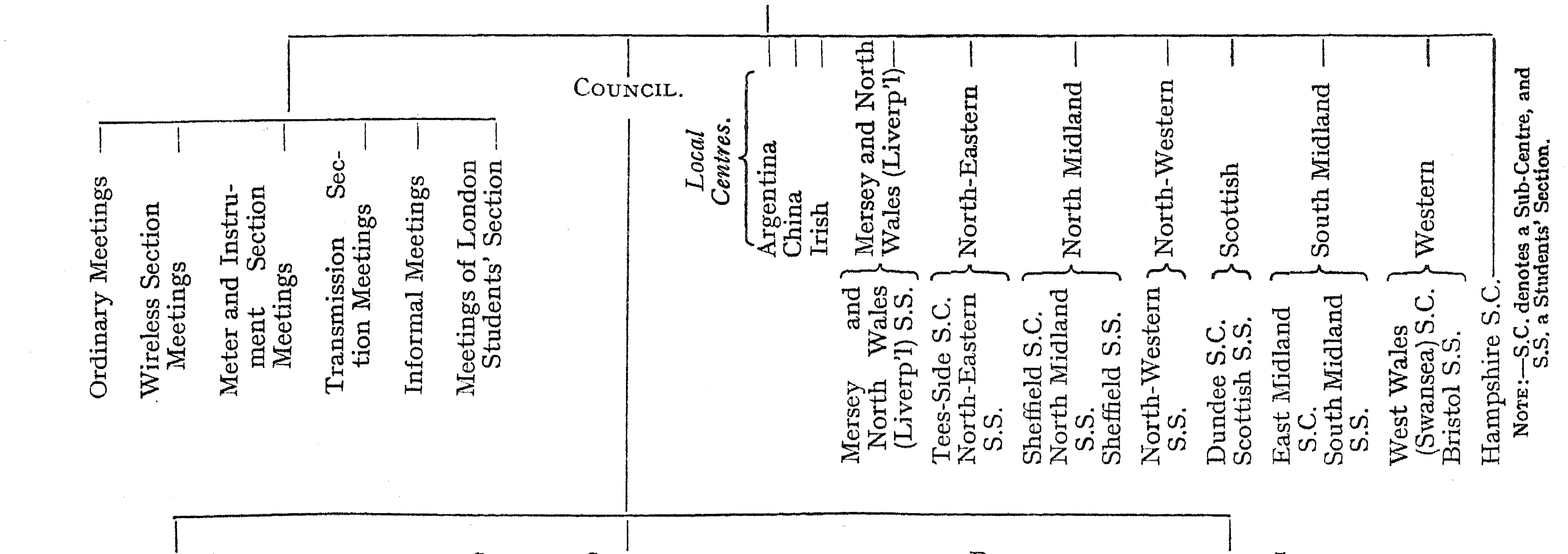
MEETINGS.

The following is a list of the meetings held during the past 12 months:—

Ordinary Meetings ..	15
Annual General Meeting	1
Annual General Meeting (Benevolent Fund)	1
Wireless Section ..	10
Meter and Instrument Section	8
Transmission Section	5
Informal Meetings ..	10
Council Meetings ..	15
Local Centres:—	
Irish	9
Mersey and North Wales (Liverpool)	10
North-Eastern ..	13
North Midland ..	11
North-Western ..	12
Scottish	13
South Midland ..	10
Western	8
Local Sub-Centres:—	
Dundee	6
East Midland ..	8
Hampshire ..	9
Sheffield	7
Tees-Side	8
West Wales (Swansea)	5
Students' Sections:—	
Bristol	8
Liverpool	11
London	13
North-Eastern ..	11
North Midland ..	9
North-Western ..	10
Scottish	12
Sheffield	11
South Midland ..	11
Committees:—	
Benevolent Fund ..	11
Electrical Engineers' Ball ..	5
Electrical Interference with Broadcasting (and Sub-Committees) ..	14
Committees—*continued.*	
Examinations ..	6
Finance	8
General Purposes (and Sub-Committees)	10
H.T. Conference, Paris (British National Committee)	2
Informal Meetings	6
Library and Museum	2
Membership ..	7
Meter and Instrument Section (and Sub-Committees)	16
Model General Conditions (and Sub-Committee) ..	2
National Certificates (England)	3
National Certificates (Scotland)	2
Overhead Lines ..	4
Overseas Activities	1
Papers (and Sub-Committees) ..	12
Scholarships ..	3
"Science Abstracts" (and "Physics" Panel)	5
Ship Electrical Equipment (and Sub-Committees)	3
Transmission Section (and Sub-Committees) ..	13
Wireless Section (and Sub-Committees)	20
Wiring Regulations (and Sub-Committees)	43
Other Committees	22
Total ..	510

APPENDIX C.

THE INSTITUTION OF ELECTRICAL ENGINEERS.



Note:—S.C. denotes a Sub-Centre, and S.S. a Students' Section.

Committees of Council.

Examinations
Finance
General Purposes
Library and Museum
Membership
Papers

Special Committees.

Benevolent Fund
Earthing to Water Mains (Joint)
Electrical Engineers' Ball
Electrical Interference with Broadcasting
Electricity (Supply) Regulations
Faraday Medal and Honorary Membership Advisory
H.T. Conference, Paris, British National Committee
Informal Meetings
International Relations
Local Centres
Meter and Instrument Section
Model General Conditions
Overhead Lines
Overseas Activities
Patent Law
Scholarships
Science Abstracts
Sea-going Electricians
Ship Electrical Equipment Regulations
Transmission Section
Wireless Section
Wiring Regulations

Technical Committees.

Applications and Plant
Electricity in Mines
Electro-Chemistry and Electro-Metallurgy
Power Stations and their Equipment
Radiological and Electro-Medical Apparatus
Telegraphs and Telephones
Traction, including Railways
Transmission and Distribution

Overseas Committees.

Ceylon
India (Bombay, Calcutta and Lahore)
New South Wales
Queensland
South Australia
Victoria and Tasmania
Western Australia
New Zealand
Transvaal

Bodies on which the Institution is Represented.

Aerodromes Advisory Board
Bristol University
British Cast Iron Research Association
British Electrical and Allied Industries Research Association
British National Illumination Committee of the International Illumination Commission
British Standards Institution
Building Industries National Council (Advisory Committee on Building Acts and Byelaws)
City and Guilds of London Institute
Council for the Preservation of Rural England
Electrical Association for Women
Electricity Commission, Conference on Rural Electrification
Engineering Joint Council
Imperial College of Science and Technology, Governing Body
Imperial Minerals Resources Conference, Copper Committee
Institute of Industrial Administration, Examinations Advisory Council
Institute of Metals, Corrosion Research Committee
Institution of Civil Engineers, Engine and Boiler Testing Committee
International Association for Testing Materials
International Congress for Scientific Management, General Council
International Electrotechnical Commission, British National Committee
Joint Fuel Committee
Leeds Municipal Technical Library Committee
Loughborough Technical College, Advisory Committee
Metalliferous Mining (Cornwall) School, Governing Body
National Certificates and Diplomas in Electrical Engineering, Joint Committees for
National Committee on Physics (Royal Society)
National Committee on Radio-Telegraphy (Royal Society)
National Physical Laboratory, General Board
National Register of Electrical Installation Contractors
National Smoke Abatement Society
Professional Classes Aid Council
Royal Engineer Board
Science Museum, S. Kensington, Advisory Council
Town Planning Institute, Committee on Overhead Transmission Lines
Union of Lancashire and Cheshire Institutes, Panel for Engineering
University College, Nottingham, Electrical Engineering Advisory Committee
War Office Mechanization Board
Women's Engineering Society
World Power Conference, British National Committee

THE INSTITUTION OF ELECTRICAL ENGINEERS.

REVENUE ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1934.

Dr. EXPENDITURE.

Year ended 31 Dec., 1933. £	s.	d.		£	s.	d.	£	s.	d.
			To Management:—						
			Salaries and Wages	14,715	18	11			
			Staff Provident Scheme	1,337	5	2			
			National Insurance	121	18	7			
			Audit Fee	73	10	0			
			Printing	621	3	9			
			Stationery and Office Requisites	575	14	9			
			Addressing Machine Requisites	57	3	8			
			Postage of Correspondence and Notices	979	2	7			
			Telephone	132	16	2			
			Travelling Expenses	362	7	3			
19,313	6	7					18,977	0	10
			,, Institution Building:—						
			Ground Rent	2,201	0	0			
			Rates	2,782	14	9			
			Heating	292	1	2			
			Lighting and Power	495	14	10			
			Insurance	204	17	9			
			Transferred to Repairs Suspense Account	1,000	0	0			
			Household Requisites and Cleaning	527	14	1			
				7,504	2	7			
			Less Rents from Tenants (after allowance for alterations)	5,260	0	0			
4,031	0	4					2,244	2	7
618	9	4	,, Furniture and Fittings (Repairs and Renewals)				509	16	8
			,, Journal:—						
			Printing	6,440	3	1			
			Postage	2,617	14	6			
			Wrappers and Envelopes	317	14	3			
				9,375	11	10			
			Less Sales and Advertisements	3,219	18	8			
4,860	4	3					6,155	13	2
57	4	4	,, Proceedings of the Wireless Section (Printing, Postage, etc.: *less* Sales)				93	19	0
662	10	7	,, Students' Quarterly Journal (Editing, Printing, Postage, etc.: *less* Sales)				564	15	8
151	10	6	,, Lending Library (Books, Printing, Postage, etc.)				189	6	7
			,, Science Abstracts:—						
			Abstracting, Editing, Printing, Postage, etc.	5,267	10	9			
			Less Subscriptions, Sales and Advertisements	4,732	19	11			
539	16	11					534	10	10
			Carried Forward				£29,269	5	4

INCOME. **Cr.**

Year ended 31 Dec., 1933. £	s.	d.		£	s.	d.	£	s.	d.
38,132	4	6	By Subscriptions				39,979	2	7
962	17	0	,, Entrance Fees and Vellum Diploma Fees				1,147	13	0
			,, Life Compositions				165	5	7
5,540	11	11	,, Dividends and Interest				5,727	3	8
80	13	9	,, Sales of "Model General Conditions"				108	7	0
19	16	10	,, Sales of "Wiring Regulations"				456	11	6
8	15	11	,, Sales of "Ship Wiring Regulations"				6	3	2
			,, Examinations:—						
			Graduateship Examination (Candidates' Fees and Sale of Papers, *less* Examiners' Fees, Printing, etc.)	643	0	3			
			National Certificates and Diplomas (Candidates' and School Authorities' Fees, *less* Assessors' Fees, Stationery, Postage, Travelling Expenses, etc.)	674	18	7			
1,105	15	0					1,317	18	10
			Carried Forward				£48,908	5	4

REVENUE ACCOUNT—*continued.*

Dr. EXPENDITURE—*continued.*

		£ s. d.	£ s. d.
	Brought Forward	.. ..	29,269 5 4
	To INSTITUTION MEETINGS:—		
	Advance Proofs	259 19 10	
	Reporting	136 10 0	
	Grant to London Students' Section	49 10 11	
	Honorarium to Kelvin Lecturer ..	25 0 0	
	Refreshments, Assistance, etc. ..	366 19 1	
	Travelling Expenses of Authors of Papers	72 14 5	
	Overseas Meetings	86 13 6	
	Epidiascope	310 15 0	
946 10 1			1,308 2 9
	,, LOCAL CENTRES:—		
	Money Grants (including Travelling Expenses of Authors of Papers) ..	3,511 13 4	
	Travelling Expenses	565 12 1	
	Faraday Lectures	506 8 1	
	Students' Lectures	160 19 8	
	Hampshire Sub-Centre Library ..	50 0 0	
4,642 6 11			4,794 13 2
255 6 6	,, PREMIUMS FOR PAPERS	.. ..	278 0 11
1,256 0 6	,, SCHOLARSHIPS	.. ..	964 4 1
	,, SPECIAL GRANTS:—		
	British Standards Institution ..	1,000 0 0	
	Electrical Research Association ..	1,250 0 0	
	National Illumination Committee ..	32 0 0	
	Paris Conference on Extra High Tension Systems	33 0 8	
	International Commission on Interference	18 13 8	
	William Froude Tank Research Fund	100 0 0	
	Union Radio Scientifique Internationale	100 0 0	
	Aerodromes Advisory Board ..	50 0 0	
	Building Industries National Council	50 0 0	
2,313 10 11			2,633 14 4
97 18 0	,, ANNUAL DINNER	.. ..	80 10 0
607 11 11	,, CONVERSAZIONE..	.. ..	614 18 3
51 19 4	,, LEGAL EXPENSES	.. ..	38 0 8
169 19 3	,, MISCELLANEOUS EXPENSES	.. ..	132 13 2
40,575 6 3			40,114 2 8
277 12 2	,, AMOUNT TRANSFERRED TO SINKING FUND (Premiums for Redemption of Cost of Building and Lease)..	277 12 2	
4,997 16 6	,, **Balance carried to Balance Sheet** ..	8,516 10 6	
5,275 8 8			8,794 2 8
45,850 14 11			£48,908 5 4

INCOME—*continued.* **Cr.**

		£ s. d.
	Brought Forward	.. 48,908 5 4
45,850 14 11		£48,908 5 4

BALANCE SHEET, 31st DECEMBER, 1934.

Dr. LIABILITIES.

	£	s.	d.	£	s.	d.
Uninvested Balances of Trust Funds	..	..	..	230	8	1
Sundry Creditors				4,940	9	1
Subscriptions received in advance				275	19	8
Repairs Suspense Account:—						
Balance at 1st January, 1934	3,409	16	4			
Amount set aside in 1934	1,000	0	0			
	4,409	16	4			
Less Expenditure on Repairs in 1934	1,284	10	3			
				3,125	6	1
Carried Forward				£8,572	2	11

ASSETS. **Cr.**

	£	s.	d.	£	s.	d.
By Institution Building and Lease:—						
Cost	73,028	6	10			
Less Reserve for Depreciation, being Surrender Values of Sinking Fund Policies	9,273	17	1			
				63,754	9	9
,, Sinking Fund (Surrender Values of Policies for Redemption of Cost of Building and Lease)				9,273	17	1
,, Library (exclusive of the Ronalds Library and Faraday Papers, which are held in trust):—						
As per last Balance Sheet	1,835	11	11			
Additions in 1934	241	18	1			
	2,077	10	0			
Less Depreciation (10 %)	207	15	0			
				1,869	15	0
,, Thompson Memorial Library (Contribution towards purchase) ..				1,000	0	0
,, Furniture, Fittings, and Apparatus:—						
As per last Balance Sheet	3,914	9	3			
Less Depreciation (5 %)	195	14	6			
				3,718	14	9
,, Sundry Debtors				2,863	13	8
,, Insurance Premiums and Sundry Payments in Advance ..				566	18	3
,, Stock of Paper, Etc., for Publications				630	16	7
,, Investments (at cost):—						
£2,600 Natal Zululand Railways 3 % Debenture Stock	2,270	12	0			
£1,500 London, Midland and Scottish Railway 4 % Preference Stock	1,513	10	4			
£2,000 Assam Bengal Railways 3 % Stock (1931 or after)	1,548	0	6			
£750 Western Australia 4 % Stock (1942–62) ..	730	8	3			
£750 Union of South Africa 4 % Stock (1943–63)	742	12	0			
£750 Madras and Southern Mahratta Railway 4% Debenture Stock (1938)	738	15	6			
Carried Forward	£7,543	18	7	£83,678	5	1

BALANCE SHEET—*continued.*

Dr. LIABILITIES—*continued.*

	£ s. d.	£ s. d.	£ s. d.
Brought Forward		.. .. ..	8,572 2 11
To Surplus of Assets over Liabilities:—			
Balance at 1st January, 1934		194,401 18 1	
Excess of Income over Expenditure for 1934 brought forward from Revenue Account		8,516 10 6	
		202,918 8 7	
Less Allocation to Supplementary Superannuation Account	£750 0 0		
Depreciation:—			
Library (*per contra*) ..	£207 15 0		
Furniture, Fittings, and Apparatus (*per contra*)	195 14 6	1,153 9 6	
			201,764 19 1
			£210,337 2 0

FRANK CRAWTER,
Honorary Treasurer.

P. F. ROWELL,
Secretary.

Cr. ASSETS—*continued.*

	£ s. d.	£ s. d.
Brought Forward	.. ..	83,678 5 1
By Investments (at cost)—*contd.*		
Brought forward	7,543 18 7	
£35 East Indian Railway "B" Annuity (1953) ..	791 5 4	
£1,500 South Australia 4 % Stock (1940–60) ..	1,494 10 6	
£6,450 3½ % War Stock	6,306 9 0	
£19,375 4 % Funding Loan (1960–90)	15,500 0 0	
£8,700 3½ % Conversion Stock (1961 or after) ..	6,651 3 3	
£11,970 11s. 4 % Consolidated Stock	10,291 6 6	
£1,000 London, Midland and Scottish Railway 5 % Preference Stock (1955)	1,020 4 6	
£4,900 North Metropolitan Power Station 5 % Guaranteed Debenture Stock (1957)	4,888 11 0	
£2,000 London, Midland and Scottish Railway 5 % Redeemable Debenture Stock (1952)	1,982 5 9	
£2,300 East Indian Railway 4½ % Irredeemable Debenture Stock	2,019 13 0	
£5,000 Commonwealth of Australia 5 % Stock (1945–75)	4,964 17 6	
£2,000 Tynemouth Corporation 5 % Stock (1947–57)	2,025 4 0	
£2,500 Stoke-on-Trent Corporation 5 % Stock (1948–68)	2,550 6 0	
£3,500 East Indian Railway 3½ % Debenture Stock (1937)	2,475 15 6	
£5,000 Brighton Corporation 4¾ % Stock (1945–75)	5,050 8 0	
£2,000 New South Wales 5¼ % Stock (1947–57) ..	2,013 19 0	
£2,600 Kenya Government 4½ % Stock (1950) ..	2,483 4 0	
£3,000 Southern Railway 4 % Debenture Stock..	2,520 5 0	
£2,500 India 4½ % Stock (1958–68)	2,329 17 9	
£2,500 Corporation of London 4½ % Debenture Stock (1940–85)	2,462 14 0	
£3,000 Birmingham Corporation 4½ % Stock (1948–68)	2,906 11 0	
£3,000 London County 4½ % Stock (1945–85) ..	2,936 11 0	
£1,000 Bootle Corporation 4¾ % Stock (1949–59)	967 12 0	
£10,000 5 % Conversion Stock (1944–64).. ..	9,888 5 10	
£2,000 Southampton Corporation 5 % Stock (1947–67)	2,027 14 0	
£2,333 London Passenger Transport Board 4½ % "A" Stock (1985–2023)..	2,110 5 0	
£2,000 Agricultural Mortgage Corporation 5 % Debenture Stock (1959–89)	2,080 11 0	
£2,400 Ayr County Council 5 % "A" Stock (1947–57)	2,484 4 0	
£2,400 Union of South Africa 5 % Stock (1950–70)	2,436 4 0	
£1,000 Nyasaland Government 4½ % Guaranteed Stock (1952–72)	1,142 13 0	
£2,500 London Passenger Transport Board 5 % "B" Stock (1965–2023)..	3,017 1 0	
(*Market value 31st December,* 1934, £148,604 13*s.* 1*d.*		119,363 10 0
,, Cash in Hands of Local Centres on 30 Sept., 1934		1,108 10 3
,, Cash:—		
At Bank	737 4 10	
At Banks in Australia and New Zealand.. ..	5,437 17 11	
In hands of Secretary	11 13 11	6,186 16 8
		£210,337 2 0

We beg to report that we have audited the Balance Sheet of The Institution of Electrical Engineers, dated 31st December, 1934, and above set forth, together with the annexed Statements of Account. We have obtained all the information and explanations we have required. In our opinion the Statements are correct and the Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the Institution's affairs according to the best of our information and the explanations given to us and as shown by the books of the Institution.

ALLEN, ATTFIELD & CO., *Auditors,*
Chartered Accountants,
24, Martin Lane, Cannon Street, E.C. 4.

26th April, 1935.

SALOMONS SCHOLARSHIP TRUST FUND (Capital).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount (as per last Account)	2,155	14	10	By Investments (at cost):—			
				£1,528 5s. 1d. New South Wales 5 % Stock (1935–55)	1,585	1	4
				£500 Cape of Good Hope 3½ % Stock (1929–49)	570	13	6
	£2,155	14	10		£2,155	14	10

SALOMONS SCHOLARSHIP TRUST FUND (Income).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount paid to Scholars in 1934	150	0	0	By Balance (as per last Account)	56	11	5
,, Balance carried to Balance Sheet*	1	13	1	,, Dividends received in 1934	95	1	8
	£151	13	1		£151	13	1

DAVID HUGHES SCHOLARSHIP TRUST FUND (Capital).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount (as per last Account)	2,000	0	0	By Investment (at cost):—			
				£2,045 Metropolitan Water Board (Staines Reservoirs) 3 % Guaranteed Debenture Stock (1922 or after)	1,998	15	0
				,, Balance carried to Balance Sheet*	1	5	0
	£2,000	0	0		£2,000	0	0

DAVID HUGHES SCHOLARSHIP TRUST FUND (Income).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount paid to Scholars in 1934	100	0	0	By Dividends received in 1934	62	2	5
				,, Interest received in 1934	0	0	6
				,, Contribution from Institution	37	17	1
	£100	0	0		£100	0	0

PAUL SCHOLARSHIP FUND (Capital).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount (as per last Account)	1,000	0	0	By Investments (at cost):—			
				£625 4 % Funding Loan (1960–90)	500	0	0
				£518 3s. 8d. Central Electricity Board 5 % Debenture Stock (1950–70)	500	0	0
	£1,000	0	0		£1,000	0	0

PAUL SCHOLARSHIP FUND (Income).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount paid to Scholars in 1934	50	0	0	By Balance (as per last Account)	20	10	6
,, Balance carried to Balance Sheet*	21	15	2	,, Dividends received in 1934	51	4	8
	£71	15	2		£71	15	2

WILDE BENEVOLENT TRUST FUND (Capital).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount (as per last Account)	3,049	16	2	By Investments (at cost):—			
				£1,308 London and North Eastern Railway 4 % First Guaranteed Stock	1,744	3	11
				£100 London County 3½ % Consolidated Stock (1929 or after)	101	8	6
				£250 New South Wales 4 % Stock (1942–62)	251	6	0
				£500 3½ % War Stock	501	9	3
				£381 15s. 1d. 4 % Funding Loan (1960–90)	300	0	0
				£200 3½ % Conversion Stock (1961 or after)	151	8	6
	£3,049	16	2		£3,049	16	2

WILDE BENEVOLENT TRUST FUND (Income).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Grants made in 1934	147	0	0	By Balance (as per last Account)	116	0	7
,, Balance carried to Balance Sheet*	76	1	2	,, Dividends received in 1934	106	7	3
				,, Interest do. do.		13	4
	£223	1	2		£223	1	2

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* Included in the total of £230 8s. 1d. shown on the Liabilities side of the Balance Sheet.

WAR THANKSGIVING EDUCATION AND RESEARCH FUND (No. 1) (Capital).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount (as per last Account)	1,700	0	0	By Investment (at cost):—			
				,, £2,000 3½ % War Stock	1,700	0	0
	£1,700	0	0		£1,700	0	0

WAR THANKSGIVING EDUCATION AND RESEARCH FUND (No. 1) (Income).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Grants made in 1934	100	0	0	By Balance (as per last Account)	60	0	0
,, Balance carried to Balance Sheet*	30	0	0	,, Dividends received in 1934	70	0	0
	£130	0	0		£130	0	0

PAGE PRIZE FUND (Capital).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount (as per last Account)	100	19	5	By Investments (at cost):—			
				£50 3½ % War Stock	50	19	5
				£51 16s. 4d. Central Electricity Board 5 % Debenture Stock (1950–70)	50	0	0
	£100	19	5		£100	19	5

PAGE PRIZE FUND (Income).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Cost of Prize awarded in 1934	4	5	0	By Balance (as per last Account)	2	4	0
,, Balance carried to Balance Sheet*	2	6	6	,, Dividends received in 1934	4	7	6
	£6	11	6		£6	11	6

THORROWGOOD SCHOLARSHIP TRUST FUND (Capital).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount (as per last Account)	1,000	0	0	By Investment (at cost):—			
				£1,005 Agricultural Mortgage Corporation 5 % Debenture Stock (1959–89)	1,000	0	0
	£1,000	0	0		£1,000	0	0

THORROWGOOD SCHOLARSHIP TRUST FUND (Income).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount paid to Scholars in 1934	50	0	0	By Balance (as per last Account)	56	19	5
,, Balance carried to Balance Sheet*	57	17	0	,, Dividends received in 1934	50	17	7
	£107	17	0		£107	17	0

SWAN MEMORIAL SCHOLARSHIP FUND (Capital).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount (as per last Account)	2,968	12	4	By Investments (at cost):—			
				£1,000 Sunderland Corporation 5 % Stock (1946–56)	1,116	13	0
				£640 Sunderland Corporation 5 % Stock (1950–60)	728	8	0
				£1,135 17s. 9d. 3½ % Conversion Stock (1961 or after)	1,123	11	4
	£2,968	12	4		£2,968	12	4

SWAN MEMORIAL SCHOLARSHIP FUND (Income).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount paid to Scholars in 1934	120	0	0	By Balance (as per last Account)	17	1	5
,, Balance carried to Balance Sheet*	20	6	10	,, Dividends received in 1934	123	5	5
	£140	6	10		£140	6	10

SUPPLEMENTARY SUPERANNUATION ACCOUNT.

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount allocated in 1934	750	0	0	By Investment (at cost):—			
,, Dividends received in 1934	19	3	4	£727 8s. 8d. 3½ % War Stock	750	0	0
				,, Balance carried to Balance Sheet*	19	3	4
	£769	3	4		£769	3	4

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* Included in the total of £230 8s. 1d. shown on the Liabilities side of the Balance Sheet.

THE BENEVOLENT FUND OF
THE INSTITUTION OF ELECTRICAL ENGINEERS.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR 1934.

Dr. EXPENDITURE.

Year ended 31 Dec., 1933. £ s. d.			£ s. d.
2,599 15 3	To Grants	£3,051 6 9	
1 5 0	*Less* Previous Grants refunded	1 5 0	
2,598 10 3			3,050 1 9
22 11 11	,, Printing, Stationery, Postages, etc.		30 4 6
1,331 16 1	,, Unexpended Balance carried to Balance Sheet		2,605 1 11
£3,952 18 3			£5,685 8 2

INCOME. **Cr.**

Year ended 31 Dec., 1933. £ s. d.		£ s. d.	£ s. d.
873 8 4	By Dividends and Interest		974 15 0
*443 11 8	,, London Electrical Engineers' Ball		209 17 1
	,, Donations of £5 and over:—		
	Mersey and North Wales (Liverpool) Centre Golf Tournament	90 0 0	
	North-Western Centre Golf Tournament	70 0 0	
	Scottish Centre Golf Tournament	19 15 0	
	North-Eastern Centre Golf Tournament	14 3 0	
	South Midland Electrical Engineers' Ball	150 0 0	
	North Midland Centre Electrical Engineers' Ball	40 0 0	
	Sheffield Sub-Centre Electrical Engineers' Ball	25 0 0	
	British Electrical Development Association, Newcastle-on-Tyne Carnival	36 0 0	
	Other donations	307 8 3	
706 4 6			752 6 3
1,032 2 3	,, Donations under £5		1,061 2 10
897 11 6	,, Annual Subscriptions		939 13 6
—	,, Legacy from the late Sir George Sutton, Bart...		900 0 0
—	,, Legacy from the late Mr. John McKenna ..		847 13 6
£3,952 18 3			£5,685 8 2

* This amount is made up as follows:—

Profit from 1933 Ball ..	£224 3 4
Balance from previous Balls	219 8 4
	£443 11 8

BALANCE SHEET, 31ST DECEMBER, 1934.

Dr. LIABILITIES.

	£	s.	d.	£	s.	d.
To Capital Account:—						
As per last Balance Sheet	£20,291	15	8			
Amount transferred from Income Account in 1934	3,568	7	0	23,860	2	8
Income and Expenditure Account:—						
As per last Balance Sheet	£2,814	14	11			
Unexpended Balance in 1934	2,605	1	11			
	5,419	16	10			
Less Amount transferred to Capital Account in 1934	3,568	7	0	1,851	9	10
,, Grants authorized but not yet disbursed				124	6	10
,, Sundry Creditors				6	9	3
,, Subscriptions and Donations received in advance				24	14	6
				£25,867	3	1

ASSETS. Cr.

	£	s.	d.	£	s.	d.
By Investments (Capital), at cost:—						
£961 7s. 7d. Cape of Good Hope 3 % Stock (1933–43) ..				950	0	0
£593 1s. 7d. New South Wales 3 % Stock (1935)				600	0	0
£420 London and North Eastern Railway 4 % First Preference Stock				503	18	3
£450 London, Midland and Scottish Railway 4 % Debenture Stock				551	0	9
£750 East Indian Railway 3½ % Debenture Stock				737	18	0
£300 London, Midland and Scottish Railway 4 % Guaranteed Stock..				333	11	6
£500 New Zealand 3½ % Stock (1940)				486	18	6
£500 Canada 3½ % Stock (1930–50)				478	16	0
£5,800 3½ % War Stock				5,783	6	1
£350 New South Wales 4 % Stock (1942–62)..				336	18	6
£2,580 4 % Funding Stock (1960–90)				2,123	15	6
£3,295 3½ % Conversion Stock (1961)				2,512	11	10
£450 Commonwealth of Australia 5 % Stock (1945–75) ..				438	16	0
£450 Tynemouth Corporation 5 % Stock (1947–57)				457	7	3
£950 Agricultural Mortgage Corporation 5 % Debenture Stock (1959–89)				988	5	6
£1,000 Southern Railway 5 % Redeemable Guaranteed Preference Stock (1957)				1,028	7	0
£1,000 Southern Railway 5 % Guaranteed Preference Stock..				1,000	3	0
£1,000 Hastings Corporation 5 % Stock (1947–67)				980	2	0
£800 London Passenger Transport Board 5 % "A" Stock (1985–2023)				808	2	6
£700 Ayr County Council 5 % Stock (1947–57)				733	7	0
£1,000 Commonwealth of Australia 4 % Stock (1955–70) ..				1,012	13	0
£900 South Essex Waterworks Co. Perpetual Debenture 4 % Stock				1,014	4	6
				£23,860	2	8
(*Market value 31st December*, 1934, *£27,831 6s. 11d.*)						
,, Investment (Income) at cost:—						
£1,050 Newcastle and Gateshead Water Co. 5 % Consolidated Preference Stock				1,513	14	6
(*Market value 31st December*, 1934, *£1,506 15s. 0d.*)						
,, Sundry Debtors				38	6	6
,, Cash:—						
At Bank	446	10	3			
In hand	8	9	2	454	19	5
				£25,867	3	1

I have audited the above Balance Sheet and Income and Expenditure Account with the Books and Vouchers and certify them to be correct, and have verified the Investments with Certificates from Banks.

JAS. ATTFIELD, F.C.A.,
Honorary Auditor.

2nd May, 1935.

DISCUSSION ON "ELECTRICAL DEVELOPMENTS IN THE U.S.S.R."*

WESTERN CENTRE, AT BRISTOL, 18TH MARCH, 1935.

Mr. W. F. Cooper: What arrangements are provided for transporting the large quantities of peat required for the peat-burning power stations? This question is particularly interesting in view of the primitive character of the transport arrangements for the original construction materials.

Mr. T. E. Harcombe: I should be glad if the author would indicate the success of industries other than the electrical industry in the U.S.S.R. The enormous increase in the electrical output suggests a corresponding success in other industries to absorb the power.

The efficient co-ordination of the various and varied types of power stations, the use made of all the available fuel resources, and the economic utilization of the "waste heat and energy," afford an excellent example of what can be done by undivided interests. Such co-operation would prove of distinct advantage to the gas and electrical industries of Great Britain. Thus full value could be obtained from coal, a greater yield of by-products being achieved without expenditure of power and certainly with less pollution of the atmosphere.

What are the natural resources of the U.S.S.R. with regard to mineral ores and other raw materials?

Mr. A. H. McQueen: The system of heating described in the paper is interesting, but one would imagine that in such a stage of electrical development "off peak" thermal-storage installations would be more practicable and more economical. Load curves of the various stations are not shown; therefore it is not possible to express an opinion as to whether this system would be advantageous in increasing the load factor. One would like to know whether this scheme has been considered and, if so, why it has been rejected. Is it only a matter of time before the limitations associated with widespread areas will render the thermal-electric station impossible, and thermal storage supersede the present method?

It is interesting to see that a short-circuit test plant is in operation. Has the author any details of the short-circuit capacities and the voltages at which these can be applied? Are any data available regarding the circuit breakers tested?

The author points to the fact that Russian engineers are over-stressing the importance of the problems relating to short-circuit conditions on switchgear and associated protective apparatus. This problem cannot be considered lightly, and one is glad to know that it is being taken seriously in a country which is rapidly forging ahead in electrical development. One would urge engineers in our own country to give consideration to these important factors and to insist that none but tested and proven switchgear shall be employed, to ensure the protection of operators, property, and of supply (the latter point is of increasing importance).

The generator protection system shown in Fig. 12 is not quite clear, and it is noted that Merz–Price generator protection has been abandoned. Why is this, and what system has been found more suitable? An elaborate and uneconomical system, together with the inability to obtain sensitive protective settings, is the salient feature of the typical lay-out shown in Fig. 12. The current is generated at 6·3 or 10·5 kV and stepped up to 35 or 110 kV through multi-winding transformers. The losses in this system must be high, and unless current transformers have readily adjustable windings, which are not desirable on account of possible open circuits, protective-gear settings will not be sensitive enough to afford the degree of winding protection required. The system of distribution employed in Russia seems clearly to call for high-voltage generation.

Messrs. C. and A. Parsons installed a turbo-alternator of 25 000 kW capacity for a working voltage of 33 kV in Brimsdown power station in 1928; this was the forerunner of many others—for the Brimsdown, Swansea, and Treforest stations, and the Salt River power station, South Africa. The overall saving effected is stated† to be equivalent to a reduction in capital cost of 10s. per kW on the first high-voltage alternator erected at Brimsdown, as compared with an ordinary plant. Does the author know whether high-voltage generation was considered by the Russian engineers? If so, why was it not adopted?

Mr. R. C. Golding: I am interested in the means employed for working a tractor satisfactorily across boggy ground, whilst cutting the peat. I gather from the author's remarks that the procedure is to cut a layer of peat 4 in. thick, allowing the next layer to dry; the process can be repeated as long as peat remains.

Mr. W. C. Bowler: I should like to inquire whether, in view of the very bad climatic conditions which exist in Russia during the winter, the Russian engineers design their overhead lines for the same conditions and factors of safety as obtain in this country. The author's lantern slides showed that the constructional work was mainly of the wooden-pole type and somewhat crude in design. One picture showed snow completely covering switchgear, insulators, etc., and I should like to know what percentage of the shutdowns can be attributed to these abnormal conditions.

Mr. W. Roberts: The author referred to the large number of labourers employed in the erection of the Russian power stations, and in the winning of the fuel;

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* Paper by Mr. A. MONKHOUSE (see vol. 76, p. 601).

† J. ROSEN: "High-Voltage Alternators," *Journal of the Junior Institution of Engineers*, 1934–35, vol. 45, p. 1.

he stated that in some cases the number is 10 times as many as would be employed on similar jobs at home. Later he mentioned the difficulty of getting skilled trained assistants for the research laboratories from among the Russians themselves. Is it a fact that to-day all grades of labour in Russia get one standard rate of pay, irrespective of the class of work they are doing? If so, it may be an explanation of the two facts referred to. Are the wages paid so low that the authorities can afford to disregard the number of people employed to do a certain job of work?

Mr. P. T. Wood: I was much interested in the author's lantern slide of the Russian telephone research building, and to note the importance evidently attached to research work by the U.S.S.R. Can the author say whether the telephone service gives equal evidence of technical advance? Is the trunk service, for instance, operated on up-to-date lines, and is there any attempt to extend the telephone to the country areas, where service can only be given at a loss?

Mr. B. L. Price: There are two points in the paper to which I should like to refer. I note from Table 2 that about 24 per cent of the steam stations are equipped for pass-out heating, yet the proportion of heat distributed to that converted into electrical energy is roughly the very small figure of 0·03 per cent. This wholesale organization of thermal-electric stations is, however, an object lesson to our electrical heating protagonists.

Regarding the efficiency of 58·7 per cent quoted for the Beresniki Chemical Works, I cannot conceive that the theoretical efficiency could be so high for the cycle quoted.

Mr. S. B. Haslam: I am very much impressed with the large amount of reinforced-concrete work shown in the author's lantern slides; it is evident that this method of construction is used very extensively in Russia. In view of the short period free from frost this is rather surprising, as it would seem that building work of this nature would be limited to a few months in each year. Obviously this is not the case, and I should be glad to know what methods are adopted to enable the work to be carried on during the cold weather. Also, I assume that the cement is all made in Russia, and I should be interested to know whether there is much satisfactory stone deposit in that country, and what cement manufacturing works are in existence.

The author referred to the growth of research in Russia, and suggested that this will benefit Europe as information comes out. My impression is that Russia will permit very little of value in the way of research results to be made known to the outside world.

Mr. H. V. Pugh: I feel that British manufacturers and engineers could and should have done more in the direction of supplying Russia with technical information and plant. Other countries, like Germany and the United States, would have been only too ready to supply all Russia's needs, and it is important that we should maintain friendly relations with Russia and foster a strong British engineering influence in that country. Russia, with the planned development described in the paper, will rapidly become a very serious rival to this country in overseas trade and services, and we cannot but admire the wonderful way in which she is carrying out the economic and industrial development of her extensive territories.

Mr. G. L. Coventon: Can the author give any information regarding the utilization of peat as a fuel in our own country and Empire? There are large deposits of peat in these islands and in our Empire, and some years ago a plant was set up to distil motor spirit from the peat; this plant, however, was not commercially successful. Has any serious consideration been given, or experiments made, with a view to utilizing peat directly as a fuel by similar methods to those used in the U.S.S.R.?

Mr. I. A. D. Pedler: The author referred to the firing of peat on the pulverized-fuel principle, and stated that the authorities had not been successful in overcoming the difficulties they had experienced in connection with the ash problem. It would appear that all the ash is taken through the first boiler pass, owing to the vortex action of the combustion air and gases. No reference was made to the details of the irregularities experienced, however, and it would therefore be interesting if the author would review some of the difficulties and the methods adopted in an endeavour to overcome them. I assume that a reasonable number of soot blowers are employed to disturb the deposited ash as far as possible, and that a large quantity of the ash is trapped in the hopper at a point where the path of the combustion gases changes its direction from the last boiler pass on its way through the economizer and air-heater tubes. I should like to ask the author whether the problem to which he referred arises from fused ash deposits on the boiler tubes, which may be difficult to remove even by means of soot blowers, or from the piling-up of ash within the boiler passes, which may be difficult to disturb for entrapment purposes on account of the temperature of the adjacent gases being too high for the introduction of soot blowers where the ash tends to collect.

A boiler efficiency of 84 per cent was mentioned; this figure may have been recorded in respect of firing on a chain-grate stoker. Was the efficiency of the boilers under discussion very much reduced owing to the piling-up of the ash within the boiler passes, or had the boilers to be taken off the range from time to time for furnace-cleaning purposes, thus abnormally increasing maintenance costs?

I should also like to know whether the principle of distributing hot water throughout Moscow and Leningrad by means of pass-out turbines was adopted owing to the scarcity of fuels suitable for household purposes, or whether it was found to be a commercial proposition as compared with the use of coal fires. It would also be interesting to know on what basis the charges are made for this service.

Mr. K. G. Glover: The map in Fig. 2, and the author's description, enable an interesting comparison to be made between the Russian transmission network and the British grid system. What is to be the kVA capacity of the proposed e.h.t. lines for linking up the various areas of the country, and will they be single- or double-circuit lines? Most of these lines are of such length that their utility is not clear; are they mainly for stand-by purposes or for bulk power transmission?

It is interesting to note that the same system of protection has been adopted for the majority of the long lines as is in use in many areas of the British grid, namely distance (impedance) protection. Can the author tell us whether the possibility of carrier-current protection was first examined and, if so, with what success? In the case of shorter lines using pilot-wire protective systems, are the pilot cables laid underground?

Mr. L. F. A. Driscoll: The monthly output of units generated during 1932 and 1933 (see Fig. 1) shows a marked reduction during what we would call the "summer" months; is this due to the lighting load? Can the author state the approximate number of hours per annum artificial lighting is required in Russia?

Concerning the interesting practice of utilizing the steam from the pass-out turbines of power stations for process work in factories and for heating water circulated through the large city areas for warming buildings, etc., what basis of charging is employed, and is there any variation for the summer and winter quarters? The high working pressures of some of the thermal stations referred to show much enterprise, and might usefully be imitated by steam-raising engineers here.

The average fuel consumption of 1·55 lb per kWh of output for the 81 stations controlled by the Commissariat of Heavy Industries represents a better performance than the operation during the same year of the 14 selected stations embraced in the South-West England and South Wales area of the Central Electricity Board, whose average fuel consumption per unit generated was 1·625 lb.; the best of the latter stations gave a figure of 1·13 and the worst 1·95, only five giving figures below the average of 1·55 for the Russian stations.

With regard to railway electrification; it would be very interesting to know some of the results obtained by the Russian engineers, and particularly the cost per mile for the electrification of the lines at present in use relative to the supply system adopted. Can the author give any further information with regard to the 20 000-volt a.c. single-phase 50-cycle overhead-contact experimental line referred to in the paper? Also, what is the consumption per head of population for a city like Moscow?

[The author's reply to this discussion will be published later.]

DISCUSSION ON

"A STUDY OF THE INDUCTION WATT-HOUR METER, WITH SPECIAL REFERENCE TO THE CAUSE OF ERRORS ON VERY LOW LOADS."*

Mr. E. W. Hill (*communicated*): I think that in his reply (see page 375) to my contribution to the discussion the author evades rather than answers my principal criticism, in which I contested his explicit statements that the anti-creep device is the cause of the large positive low-load errors. It seems that the author now wants to introduce a factor, namely the alteration of the low-load adjustment to procure a "satisfactory value of the starting load," which was never touched on in the paper. In fact the paper, dealing as it does in particular detail with "the cause of errors on very low loads," makes no reference either to the low-load adjustment or to its important function of providing means for regulating the value of the shunt torque.

The author's new argument can, I think, be fairly stated as follows: The anti-creep device impairs the "starting" qualities of a meter; in order to restore these qualities to what they would be without the anti-creep device it is necessary to increase the shunt torque by advancing the low-load adjustment, with the result that the low-load errors are greater and more positive with the anti-creep device than they would be without it.

I am inclined to agree, subject to experimental confirmation, that this is a reasonable proposition, but, unfortunately for the author, it is one quite different from any that were advanced in the paper. I want especially to draw attention to the significance of the position now occupied by the anti-creep device in the new proposition's chain of causation. The links in this chain seem to me to be: (*a*) the large positive errors at low loads, caused by (*b*) the more advanced setting of the low-load adjustment, in turn caused by (*c*) the action of the tester who thus regulates the meter, which is prompted by (*d*) the adverse effect of the anti-creep device on the starting load as judged by the tester.

Now although the anti-creep device may justly be regarded as the immediate cause of the bad "starting," it is quite clear that, in the sequence I have just cited, the anti-creep device is actually only an indirect "cause" of the final effect (large positive errors at low loads), from which it is of necessity separated by several intermediate steps. Furthermore, and this is more serious, it is not a true physical cause, as although (*a*) must follow from (*b*), and (*b*) must follow from (*c*), yet (*c*) need not necessarily follow from (*d*), for obviously the matter depends on the volition of the tester. In short, the relation between (*c*) and (*d*) is not a physical one at all, but a kind of psychological one. The author's new proposition thus involves the recognition of the anti-creep device as having an indirect non-physical relation to the alleged "effect," and so it really seems to be torturing our language to call it a "cause." Just as though, for instance, I claimed a cracked jewel in a meter's bottom bearing as the "cause" of large positive low-load errors because the tester found it necessary, after the appearance of this jewel defect, to advance the low-load adjustment in order to restore the starting load to its previous value.

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* Paper by Dr. T. Havekin (see page 355).

Now it must in fairness be remembered that I was criticizing the statements in the *paper*, and I honestly think that no one could read that paper carefully without being struck by the fact that the author from first to last (including all the mathematics) wrote as though it was an efficient, immediate, physical cause he was looking for, and finally in his opinion found, in the anti-creep device. Never was there so much as even a hint that his view was other than this.

If the author now chooses to change his ground, well and good. But he certainly does not thereby rebut my criticism; on the contrary, by implication he fully justifies my refusal to admit the anti-creep device as a "cause" in the universally accepted sense of that word.

Should I by chance have done the author the injustice of misreading his paper, I shall be happy to have him point out any passages which indicate the anti-creep device as being something other than an immediate physical cause of the large positive low-load errors; and then, of course, I shall be ready to apologize to him for having aimed some of the shafts of my criticism at a non-existent target.

Dr. T. Havekin (*in reply*): It was clear from Mr. Hill's first criticism that it would be necessary in reply to direct his attention to the importance of starting load, but I little realized that he had so completely lost sight of it that he would regard my reference to it as a new argument. Nevertheless, the reference has borne fruit. He now recognizes some connection between the anti-creep device and the low-load errors, but he is not yet prepared to accept the statement, in my conclusion to the analysis, that the anti-creep device is responsible for the positive errors on very low loads. Instead, he prefers to say that the anti-creep device is actually only an indirect cause of the large positive errors at low loads. Lest, perhaps, it should be difficult to see the point of his objection, he constructs a chain of causation and uses a tester as one of the links. It would presumably be one such tester who produced curve A in Fig. A for Mr. Hill, because he tells us that the tester need take no action to remedy the adverse effect of the anti-creep device on the starting load, i.e. (*c*) need not necessarily follow from (*d*). This savours of the nature of a revelation, but as to whether it would command the approval of any chief of any meter-testing department I have the gravest doubts.

The paper deals with a meter which has good starting qualities, large low-load errors, and an anti-creep device which is shown by the analysis to be over-effective. By hypothesis large low-load errors are intolerable, and on this special basis the meter is a bad one. We want to make it into a good meter. A good meter *must* have good starting qualities. Mere manipulation of the low-load adjustment cannot make the errors small without injuring the starting, but if the anti-creep device is first suitably modified, then the meter can be adjusted to have good starting qualities and small low-load errors. This is all made evident by a little reflection on the analysis, and in the Conclusion to the paper it is summarized in the words "the anti-creep device is responsible for the positive errors on very low loads."

In general, all induction meters, whether good or bad in our special sense, *must* have good starting qualities, so that large positive errors are inevitable with an over-effective anti-creep device.

If small errors and good starting are associated with a given meter, then the anti-creep device is obviously *not* over-effective, and is either of good design or fortunate choice.

If Mr. Hill will turn to page 357 and read (ii) Section 3, he will find it rather difficult to justify his statement that "the paper . . . makes no reference either to the low-load adjustment or to its important function of providing means for regulating the value of the shunt torque."

PROCEEDINGS OF THE INSTITUTION

882ND ORDINARY MEETING, 14TH MARCH, 1935.

Prof. W. M. Thornton, O.B.E., D.Sc., D.Eng., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 28th February, 1935, were taken as read and were confirmed and signed.

Messrs. R. A. MacMahon and W. G. Radley, B.Sc. (Eng.), were appointed scrutineers of the ballot for the election and transfer of members and, at the end of the meeting, the President reported that the members whose names appeared on the list (see vol. 76, page 599) had been duly elected and transferred.

The President announced that, during the month of February, 617 donations and subscriptions to the Benevolent Fund had been received, amounting to £225. A vote of thanks was accorded to the donors.

A paper by Mr. E. S. Byng, Member, entitled "The Engineer Administrator" (see page 491), was read and discussed.

The meeting terminated at 8 p.m. with a vote of thanks to the author, which was moved by the President and carried with acclamation.

883RD ORDINARY MEETING, 28TH MARCH, 1935.

Mr. W. E. Highfield, Vice-President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 14th March, 1935, were taken as read and were confirmed and signed.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

A paper by Mr. W. D. Horsley, Associate Member, entitled "The Stability Characteristics of Alternators and of Large Interconnected Systems" (see page 573), was read and discussed.

The meeting terminated at 7.25 p.m. with a vote of thanks to the author, which was moved by the chairman and carried with acclamation.

884TH ORDINARY MEETING, 4TH APRIL, 1935.

Prof. W. M. Thornton, O.B.E., D.Sc., D.Eng., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 28th March, 1935, were taken as read and were confirmed and signed.

The President announced that, during the month of March, 404 donations and subscriptions to the Benevolent Fund had been received, amounting to £186. A vote of thanks was accorded to the donors.

Prof. E. W. Marchant, D.Sc., Past-President, then delivered the Eleventh Faraday Lecture, entitled "Electricity in the Life of To-day." The meeting terminated at 7.10 p.m. with a vote of thanks to the lecturer, which was moved by the President and carried with acclamation.

885TH ORDINARY MEETING, 11TH APRIL, 1935.

Prof. W. M. Thornton, O.B.E., D.Sc., D.Eng., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 4th April, 1935, were taken as read and were confirmed and signed.

Messrs. R. H. Coates and P. L. Tabois were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the President reported that the members whose names appeared on the lists (see vol. 76, page 718) had been duly elected and transferred.

A paper by Sir Noel Ashbridge, B.Sc.(Eng.), Member, Mr. H. Bishop, B.Sc.(Eng.), Member, and Mr. B. N. MacLarty, entitled "The Droitwich Broadcasting Station" (see page 437), was read and discussed.

The meeting terminated at 7.50 p.m. with a vote of thanks to the authors, which was moved by the President and carried with acclamation.

886TH ORDINARY MEETING, 2ND MAY, 1935.

Prof. W. M. Thornton, O.B.E., D.Sc., D.Eng., took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 11th April, 1935, were taken as read and were confirmed and signed.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

The President announced that, during the month of April, 260 donations and subscriptions to the Benevolent Fund had been received, amounting to £91. A vote of thanks was accorded to the donors.

Messrs. H. J. Allcock, A. Middleton, and J. F. Shipley, were appointed scrutineers of the ballot for the election of new Members of Council.

The President: Once in every year the Council invite a distinguished scientist to speak to us on the subject he has made peculiarly his own and to deliver the Kelvin Lecture. This evening we are to hear Sir William Bragg. On the present occasion we have the further pleasure of presenting the Faraday Medal, which has been awarded by the Council to Dr. F. B. Jewett of New York, on whose great services to the cause of international communication I propose to ask one of our Past-Presidents, Mr. F. Gill, to speak.

Mr. F. Gill: Once upon a time when the longest distance over which commercial speech was possible was the 950 miles between New York and Chicago the then President of the American Telephone and Telegraph Co. requested that efforts should be made so to extend the distance that by the San Francisco Exposition in 1915—six years ahead—it should be possible to speak over the 3 600 miles, from coast to coast. It was not then known how to do so, and the request involved the creation of a new art. Shortly afterwards the chief engineer of that company entrusted Dr. F. B. Jewett with the organization of the laboratory work to bring science to the assistance of the many problems involved. By 1911, roughly two years afterwards, the distance had been doubled. Service was then in operation between New York and Denver—2 040 miles. Still it was not known how to get over the rest of the distance. In January, 1915, there was opened—in time to meet the request of six years before—a service between New York and San Francisco. In October of the same year the first spoken words came across the Atlantic—that time from Arlington to Paris. A few years later, in 1923, the first connected one-way conversation at a predetermined time was transmitted by radio across the Atlantic—this time from Long Island to London. In January, 1927, a commercial telephone service was opened between England and the United States.

In each instance the scientific work of the laboratory under the administration of Dr. F. B. Jewett was vital. For about 25 years Jewett has been the creator and the administrator of a very remarkable industrial research organization. At the present time, under a change of name, he is President of the Bell Laboratories which, I think, have rather a unique position in that they do for the Bell telephone system of America practically the whole research of one national industry; and they do it in rather a unique way in that the research is for the bettering of the service to the public and not for the manufacture of goods to be sold.

I want to mention just a few instrumentalities which have arisen out of those laboratories during Jewett's administration—long-distance cables, the practical development of inductive loading, the practical development of many kinds of telephone and telegraph valves, rotary and panel machine switching, high-speed submarine telegraphy, means for telephone service over any earth distance, land or sea, carrier-current telephony and telegraphy. Apart from his Ph.D., gained in his student days, his work has been recognized by something like eight Honorary Doctorates. He is a Past-President of the American Institute of Electrical Engineers; he is an Honorary Member of the Institute of Electrical Engineers of Japan; he is a Member of the American Academy of National Science, and he holds the Edison Medal. There is a great deal more, but those are important.

His work has demonstrated that industrial research is a thing which no technical industry can afford to ignore; that science can be carried on under the conditions of modern business; that scientific men of high training and creative imagination can work co-operatively with others for the betterment of service and under the conditions imposed by industry. Lastly, he has demonstrated in himself that the leaders necessary for that kind of work can be found from the scientific personnel. I submit that such services do come within the words of the Faraday conditions, viz. "service to electrical science."

The President: Before I ask Dr. Jewett to accept the Medal, I should like to read the terms of the award. "The Faraday Medal of the Institution of Electrical Engineers was founded in 1921 to commemorate the Fiftieth Anniversary of the first Ordinary Meeting of the Society of Telegraph Engineers, now the Institution of Electrical Engineers. The Medal is awarded by the Council not more frequently than once a year either for notable scientific or industrial achievement in electrical engineering, or for conspicuous service rendered to the advancement of electrical science, and without restrictions as regards nationality, country of residence, or membership of the Institution."

The Medal was then presented by the President to Dr. F. B. Jewett amid applause.

Dr. F. B. Jewett: I do not know that I can give any greater tangible evidence of my appreciation of this honour which has been conferred upon me than is shown by my physical presence here in London. There is nothing which the engineering profession could bestow on me which I should like better to have than this Medal, bearing as it does the name of the man who means so much to all of us who have followed in the paths which he marked out. In the minute or two allotted me to express my appreciation, I should like to say that Mr. Gill and the President have both mentioned what I myself feel is my contribution to the field of electrical science, namely, my endeavour during the last 30 years to organize industrial research in the field of electrical communication and to enlarge the scope of engineering by fuller use of the work of the fundamental science laboratories.

As I look back over the years, it seems to me that I must have been born under a very lucky star—lucky in the education which I had and which was unique in its time, although quite fortuitous so far as I was concerned. It began with an engineering education of the rather formalized sort common enough in the 90's, but this was supplemented by four very marvellous years at the University of Chicago, the last two of which, as A. A. Michelson's research assistant, gave me an insight into fundamental science, which at that time was not the usual equipment of a man trained in engineering. Then came the opportunity to go into an industrial field for the purpose of bringing to bear in that field the methods and knowledge of fundamental science. Here, again, the situation was most opportune for me. The telephone industry had about reached the end of its ability to progress by employing a strictly engineering technique ; and at the same time science had advanced far enough to provide new material which, properly handled, promised to be rich in value to the electrical industry and particularly to the communication field. It was my good fortune to receive my introduction to the telephone industry at that juncture.

As sometimes happens, it developed in this instance that progress would be made most rapidly by an indirect attack. The key to the situation was not so much the solution of specific problems in the communication field as it was the development of a supply of properly trained workers. It soon became apparent that if we were going to succeed in this adventure, something must be done in our institutions of learning. The men who were training for research work in physics, chemistry, and mathematics, in our universities were headed not for industry but for the teaching profession, and their number was scarcely sufficient for the needs of this profession. I was therefore one of those who early set themselves the task of stimulating among the young men in universities who were taking up investigative work an interest in industrial research. In the course of perhaps a decade, we succeeded very well, and a little later we were somewhat overwhelmed with our success. One of our major considerations became that of trying to inoculate other industries with the desire to make use of this same material of which we had tapped the source. Concurrently, of course, there was, and has continued, an actual attack on the specific technical problems of the industry. I therefore feel that my chief role during the past 30 years has been that of creating an organization designed to make industrial research profitable, by turning to practical ends under controlled conditions a portion of the vast stream of new knowledge which is coming out of the world's fundamental research laboratories.

As to Mr. Gill's mention of the achievements of this industrial research organization—the research laboratories of the Bell Telephone System—it would be quite improper to allow the record to stand as he gave it; those achievements are primarily the work of my associates, and in them there is relatively little personal credit due to me. In offering this brief expression of gratitude to the Institution for conferring the Faraday Medal upon me, I therefore take great pleasure in joining it with a tribute to my many associates, who have been loyal friends and coadjutors all these years.

The President: I think it would be proper if I called attention to the fact that there are three other recipients of the Faraday Medal in the room, namely, Col. Crompton, Sir Ambrose Fleming, and Sir Frank Smith.

Sir William Bragg then delivered the Twenty-sixth Kelvin Lecture on "The Molecular Structure of Dielectrics" (see page 737).

A vote of thanks to the lecturer, proposed by Mr. P. V. Hunter, C.B.E., Past-President, and seconded by Lieut.-Col. A. G. Lee, O.B.E., M.C., Vice-President, was carried with acclamation and the meeting then terminated.

63RD ANNUAL GENERAL MEETING, 16TH MAY, 1935.

Prof. W. M. Thornton, O.B.E., D.Sc., D.Eng., President, took the chair at 6 p.m.

The notice convening the meeting was taken as read.

The minutes of the Ordinary Meeting held on the 2nd May, 1935, were also taken as read and were confirmed and signed.

Messrs. J. D. Billington and G. Waters were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the President reported that the members whose names appeared on the list (see page 147) had been duly elected and transferred.

The Premiums (see vol. 76, page 717, and vol. 77, page 147) which had been awarded by the Council for papers during the session were then announced by the President.

The President next summarized the Annual Report of the Council (see page 860) and moved its adoption. The motion was put to the meeting and carried unanimously.

Mr. J. I. Bernard suggested that more attention should be given to papers on the utilization of electricity for light, heat, and power.

Mr. D. J. Bolton supported Mr. Bernard and also suggested that the arrangements for the discussions should be such as to permit of a larger number of members taking part, even if this necessitated cutting down some of the speakers to a minute or two. He quoted an instance in which figures very damaging to electrical development were given in a paper in December and were not challenged until the following May because certain speakers who had given in their names for the discussion were not called upon.

Mr. L. W. Phillips suggested that, before sending out its list of nominees for election to the Council, the general body of members should be invited by the Council to make nominations, and that the two sets of nominations should be sent out at the same time. He would also have liked to have seen an Educational Section of the Institution set up. Such a group would discuss problems and methods of presentation of electrotechnology and its allied subjects. It would lead to a closer and more vital connection between training and industrial research. Teaching of works methods and design was often behind modern practice, and an Educational Section could do much to remedy this by bringing together those engaged in training and in industry.

Mr. F. W. Crawter (*Hon. Treasurer*): I beg to move that the Statement of Accounts and Balance Sheet for the year 1934* as presented be received and adopted. If members will turn to the Revenue Account and look at the right-hand column showing the Income, they will see that the receipts from subscriptions, entrance fees, and life compositions, amount to £41 292, which is an increase of £2 197 over the previous year's figure. Dividends and interests are also up by £187. The sales of the Institution's publications also show an increase of £462, which is largely due to the issue of a new edition of the Wiring Regulations. The receipts from Examinations are up by £212. On the Expenditure side, the cost of management is £336 less than last year, owing primarily to the fact that we did not issue a List of Members, which saves us £300 in printing. The net cost of the Institution Building is appreciably less than it was last year. It is down by £1 787, owing to the receipts from our tenants this year being £5 260, an increase of £2 109 over what they were last year. The cost of the *Journal* is mounting up. The increase this year is £1 295, which is explained by the fact that we published 1 466 pages as against 1 194 pages last year; this, of course, also increased the cost of postage. The cost of the *Students' Quarterly Journal*, which I think everybody will agree is doing very good work, is down by nearly £100, owing to the fact that we were able to make very much better terms for having it printed. The cost of *Science Abstracts* is about the same this year as last. The cost of the Institution's meetings is up by about £300 as compared with last year because we have purchased an epidiascope at a cost of £310, which I think will be a very useful article for us to have. The cost of Scholarships is down by £292 as compared with last year, not so many having been awarded. The special grants are up by £320, owing to our having given £300 to the last four names in the list. The net effect of the Revenue Account is that we carry to the Balance Sheet £8 516.

Turning to the Balance Sheet, on the Assets side the Institution Building stands at the price we paid for it, the reserve for depreciation being met by a sinking fund. The value of the Library was taken as at the 31st December last, after a deduction for depreciation. Our investments appear at cost, namely £119 363, and members will notice that the valuation on the 31st December amounted to £148 604. A more recent market valuation on the 30th April showed £146 131, which is down a little as compared with December, but still shows an increase of £26 768 as compared with the purchase price.

Turning to the Liabilities side, it will be seen that the surplus of Assets over Liabilities amounts to £201 765, which is an increase of £7 363 compared with last year.

I forgot to mention when dealing with the Assets side that we have cash at banks in Australia and New Zealand of £5 437, which is on deposit at 2½ per cent for the reason that we cannot get it over to this country without a considerable loss on exchange.

I think that is all I have to say with regard to the Accounts, but before I sit down I should like to express my very great appreciation to Mr. Rowell and his staff for their courtesy and the ever ready help which they have given me on all possible occasions.

The resolution was seconded by **Lieut.-Col. K. Edgcumbe, T.D.**

After **Mr. Crawter** had replied to a question raised by **Mr. W. C. P. Tapper,** the motion for the adoption of the Accounts was put to the meeting by the President and carried unanimously.

The President: I now move "That the best thanks of the Institution be accorded to the following officers for their valuable services during the past year: (*a*) the Hon. Secretaries of the Local Centres; (*b*) the Local Hon. Secretaries abroad; and (*c*) the Hon. Treasurer, Mr. F. W. Crawter."

The resolution was seconded by **Prof. E. L. E. Wheatcroft** and was carried with acclamation.

The President then moved "That Messrs. Allen, Attfield and Co. be appointed auditors for the year 1935–36," and the motion was carried unanimously.

This concluded the formal business of the Meeting.

Talking-films of the following were then exhibited:—Sir William Bragg, O.M., K.B.E., M.A., D.Sc., F.R.S., Colonel R. E. B. Crompton, C.B., F.R.S., Sir Richard Glazebrook, K.C.B., D.Sc., F.R.S., Sir Oliver Lodge, D.Sc., F.R.S., Mr. W. M. Mordey, and Sir Joseph Thomson, O.M., M.A., F.R.S.

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* See page 870.

THE BENEVOLENT FUND.

37TH ANNUAL GENERAL MEETING, 16TH MAY, 1935.

Prof. W. M. Thornton, O.B.E., D.Sc., D.Eng., President, took the chair at 5.30 p.m.

The notice convening the meeting was taken as read. The minutes of the 36th Annual General Meeting held on the 10th May, 1934, were also taken as read and were confirmed and signed.

The Report of the Committee of Management (see below) and the Statement of Accounts for the year 1934 (see page 876) were presented and, on the motion of the Chairman, seconded by Mr. J. F. Shipley, were unanimously adopted.

The Chairman was asked to convey to Mr. P. F. Rowell the thanks of the meeting for the special donation of 25 guineas which he had made to the Benevolent Fund as a thanksgiving for his 25 years' Secretaryship of the Institution.

Mr. L. W. Phillips suggested that a special Jubilee effort be made to increase the income of the Fund.

Mr. W. C. P. Tapper pointed out that the average amount subscribed per member to the Fund was ½d. per week and suggested that members be asked to increase this amount to 3d.

Mr. E. F. Sharp requested that the question be considered of allowing contributors to appoint their own representatives on the Committee of Management.

On the motion of the Chairman it was resolved that Mr. J. Attfield, F.C.A., be appointed Honorary Auditor for the year 1935.

The Chairman reported that, under Rule 15, the Council had appointed the following Committee of Management for the year 1934–35:—

The President (*ex-officio*);
A. H. M. Arnold, D.Eng.,
J. R. Beard, M.Sc.,
F. W. Crawter,
V. Z. de Ferranti,
W. McClelland, C.B., O.B.E.,
Johnstone Wright,
} representing the Council;
J. F. W. Hooper,
P. Rosling,
J. F. Shipley,
} representing the contributors;

together with the Chairmen of the Local Centres in Great Britain and Ireland.

REPORT OF THE COMMITTEE OF MANAGEMENT OF THE BENEVOLENT FUND FOR 1934.

CAPITAL.

The Capital Account stood on the 31st December, 1934, at £23 860 2s. 8d., which is invested. During the year an amount of £3 568 7s. was transferred to this Account from the Income Account.

RECEIPTS.

The Income for 1934 from dividends, interest, and annual subscriptions, was as follows:—

	£	s.	d.
Dividends and Interest	974	15	0
1 751 Annual Subscriptions ..	939	13	6
	£1 914	8	6

In addition to the foregoing, the Fund benefited during the year by the following donations:—

	£	s.	d.
South Midland Electrical Engineers' Ball ..	150	0	0
Mersey and North Wales (Liverpool) Centre, Golf Tournament	90	0	0
North-Western Centre, Golf Tournament ..	70	0	0
"Dynamicables"	50	0	0
North Midland Centre Electrical Engineers' Ball	40	0	0
British Electrical Development Association (Donation from proceeds of Carnival at Newcastle-on-Tyne)	36	0	0
"The Twenty-Five Club"	26	5	0
Sheffield Sub-Centre Ball	25	0	0
Scottish Centre, Golf Tournament	19	15	0
Western Centre and West Wales Sub-Centre	17	19	6
North-Eastern Centre, Golf Tournament ..	14	3	0
North Midland Centre (collections at meetings)	10	14	3
Incorporated Municipal Electrical Association	10	10	0
National Register of Electrical Contractors	10	10	0
Argentine Centre	7	14	6
Henley's Telegraph Works Co., Ltd. ..	25	0	0
General Electric Co., Ltd.	10	10	0
Messrs. Kennedy and Donkin	10	10	0
Messrs. Merz and McLellan	10	10	0
P. F. Rowell (in grateful thanksgiving for the privilege of 25 years' Secretaryship of I.E.E.)	26	5	0
Anonymous	10	0	0
W. B. Esson	10	0	0
The late Sir George Sutton, Bart.	10	0	0
V. E. Faning	5	5	0
Lord Hirst of Witton	5	5	0
H. Marryat	5	5	0
P. Rosling	5	5	0
L. C. F. Bellamy	5	0	0
F. H. Clough	5	0	0
J. M. Donaldson	5	0	0
R. G. Kilburne	5	0	0
H. E. Morrow	5	0	0
G. H. Nisbett	5	0	0
K. A. Scott-Moncrieff	5	0	0
E. A. Short	5	0	0
and 2 949 donations of under £5	1 061	2	10
	£1 813	9	1

The accumulated balance of the Income and Expenditure Account amounted on the 31st December, 1934, to £1 851 9s. 10d., of which £1 513 14s. 6d. was invested, and £200 was on deposit with the Institution bankers.

DONORS AND SUBSCRIBERS.

Lists of the names of donors and subscribers are issued to members of the Institution annually.

The Committee of Management desire to acknowledge their indebtedness to the donors and subscribers and to intimate that, apart from donations, the Committee will be grateful for annual subscriptions of any amount, as the Committee are anxious that the Capital Account should be steadily augmented so as to strengthen the financial position of the Fund.

GRANTS.

Applications for assistance were made by or on behalf of 52 persons during 1934, and the Committee, after due consideration, made grants in 50 cases. The figures for 1933 were 59 and 53 respectively.

The total amount of the grants was £3 051 6s. 9d., which compares with £2 599 15s. 3d. for 1933.

BEQUESTS.

The Committee are gratified to report that during the year the Fund benefited by two legacies, viz. £900 from the estate of the late Sir George Sutton, Bart., who for many years was an annual subscriber to the Fund, and £847 13s. 6d. from the estate of the late Mr. John McKenna.

WILDE FUND.

The Capital Account stood on the 31st December, 1934, at £3 049 16s. 2d., all of which is invested and brings in an annual income of about £105 12s.

The balance standing to the credit of the Income Account (from which, under the Trust Deed, only full Members and their dependants can benefit) on the same date was £76 1s. 2d.

Grants amounting to £147 were made from this Fund during the year.

ELECTRICAL ENGINEERS' BALL.

The annual Electrical Engineers' Ball, held on the 9th February, 1934, realized a surplus of £209 17s. 1d., which was handed over to the Fund.

INSTITUTION NOTES.

Index to Journal.

Any member who proposes to bind the current volume of the *Journal* and would like to have an extra copy of the Index, for filing apart from the bound copy of the *Journal*, can obtain an additional copy on application to the Secretary.

Members from Overseas.

The Secretary will be obliged if members coming home from overseas will inform him of their addresses in this country, even if they do not desire a change of address recorded in the Institution register.

The object of this request is to enable the Secretary to advise such members of the various meetings, etc., of the Institution and its Local Centres, and, when occasion arises, to put them into touch with other members.

Communications from Overseas Members.

Overseas members are especially invited to submit, for publication in the *Journal*, written communications on papers read before the Institution or published in the *Journal* without being read. The contributor's country of residence will be indicated in the *Journal*. In this connection a number of advance copies of all papers read before the Institution are sent to each Local Hon. Secretary abroad to enable him to supply copies to members likely to be in a position to submit communications.

Overseas Members and the Institution.

During the period 1st September to 30th November, 1935, the following members from overseas called at the Institution and signed the "Attendance Register of Overseas Members":—

Andrews, J. E. (*Shanghai*).
Ashmawy, S. A. (*Edfu East, Egypt*).
Atchison, A. F. T., B.Sc. (*Cairo*).
Brasher, W. K., B.A. (*Jerusalem*).
Brown, John C., B.Sc. (*Lahore*).
Cater, C. (*Ceará, Brazil*).
Dave, N. M., B.Sc.(Eng.) (*Ahmedabad*).
Giles, P. A. (*Durban*).
Jackson, P. S. E. (*Calcutta*).
King, L. H. (*Hong Kong*).
Knight, S. A., B.Sc.(Eng.), (*Shanghai*).
Leak, B. W. (*Cairo*).
Low, Major P. D., O.B.E. (*Lucknow*).
Marsh, E. R. (*Calcutta*).
Ogden, Captain G. W., B.A., R. Signals (*Khartoum*)
Roberts, C. L. (*Jerusalem*).
Scudamore, C. J. W. (*Te Aroha, N.Z.*).
Thacker, M. S., B.Sc (*Calcutta*).
Turrell, F. H., B.Sc.(Eng.) (*Johore, Malay States*).
Villanueva, A. (*Madrid*).
Wilkins, F. J. (*Nigeria*).

OBITUARY NOTICES.

FREDERICK ARTHUR BOND, whose death occurred on the 2nd January, 1935, at the age of 58, was a native of Glamorgan. He received his technical training at University College, Bristol, and was subsequently apprenticed to Messrs Peckett and Sons, Atlas Engineering Works, Bristol, with whom he remained for 5 years. For the next 2 years he was engaged with Messrs. Jolin and Co., Bristol, in the manufacture of electrical machinery and apparatus. In March, 1899, he joined the staff of the City of London Electric Lighting Co., Bankside, and remained as an assistant engineer with this company for 4 years. In December, 1902, he became chief assistant engineer to the Ilford Urban District Council, and in 1904, on the inauguration of the Heston and Isleworth Urban District Council electricity undertaking, he was appointed the first electrical engineer of that undertaking. He held this position for 2 years and then, in 1906, became borough electrical engineer at Battersea. On his appointment to the latter position the capital expenditure on the undertaking amounted to £237 150; this has now been increased to £1 693 948. The units sold increased from 2 159 187 to 78 891 544 in 1933, the cost per unit sold has been reduced from 1·45d. to 0·40d. per unit, and the plant capacity has been increased from 2 743 kW to 52 350 kW. He was elected an Associate Member of the Institution in 1902, and became a Member in 1913. H. F. J. T.

JOSEPH BEVAN BRAITHWAITE was born in London on the 5th October, 1855, and died on the 30th November, 1934. He was educated at Kendal School and commenced to read for the Bar. An invitation to join his uncle's stockbroking firm, however, determined his business career, and he became, in due course, senior partner of the firm of Foster and Braithwaite, a position which he held from 1888 until his retirement in 1922. His City interests brought him into touch with the electrical supply industry in its earliest days, and in conjunction with Mr. Emile Garcke, Mr. George Herring, and other well-known pioneers, he was largely instrumental in providing finance for the foundation and development of the new industry. On the formation of the Anglo-American Brush Electric Light Corporation in 1880, Mr. Braithwaite became the chairman, first of the western subsidiary branch, and later of the parent concern under its altered title of the Brush Electrical Engineering Co., a position which he held until 1901. In 1890 the Electric and General Investment Co. was formed, Mr. Braithwaite being one of the original directors, and chairman from 1906 up to the time of his death. This company was instrumental in promoting many electrical undertakings, notably the British Electric Traction Co. in 1896, through which Mr. Braithwaite's electrical interests were spread still more widely. In 1899 he was largely instrumental in the formation of the Electric Light and Traction Co. of Australia, which later divided into two separate undertakings—the Melbourne Electric Supply Co. and the Adelaide Electric Supply Co. He was chairman of the parent concern and subsequently of the Melbourne and Adelaide companies up to 1921, when the control and management of both concerns was transferred to Australia. He was also interested, in the early years of this century, in the Utah Light and Railway Co. operating at Salt Lake City; but his two main interests were the City of London Electric Lighting Co. and the County of London Electric Supply Co. He was an original director of the latter company and was for many years chairman until his retirement in 1919. He was largely concerned in the promotion of the City of London Co., and was chairman of the company from 1906 to 1934. He took the keenest interest in its affairs right up to the time of his death, and the chairmanship of this company, and of its subsidiary, the Bankside Investment Trust, and the chairmanship of the Electric and General Investment Co., were the only interests that he retained after his general retirement from business in 1922. He was elected a Member of the Institution in 1893.

WALTER JAMES COLES died on the 25th July, 1935, at the age of 60. He received his technical training at the Finsbury Technical College from 1893 to 1895, and continued at the College until 1896 as assistant to the late Prof. Perry. In that year he joined the firm of Maxted and Knott, consulting engineers, Hull, as a draughtsman. In 1897 he became assistant manager to Messrs. P. J. Neate, Rochester. He held this position until 1899, when he joined the County of London Electric Lighting Co. as shift engineer. In 1900 he was appointed manager and engineer to the Modern Brick Co., Essex. Two years later he became a partner in the firm of Maxted, Knott, and Coles, consulting engineers, which position he held until 1910, when he set up a practice in London as a consulting engineer. In 1922 he became a director of Messrs. Edgar Allen and Co., Sheffield, and at the time of his death was still a director. He was elected a Student of the Institution in 1895, an Associate in 1898, an Associate Member in 1902, and a Member in 1911. W. H. F.

JOHN EDWARD DONOGHUE was born in Sheffield in 1874, and died in December, 1934. He received his technical training from 1887 to 1890 at Victoria University, Sheffield, and with the Tasker Engineering Co. In 1890 he was appointed shift engineer with the Sheffield Electric Light and Power Co., later becoming chief assistant to the deputy manager. In 1895 he took the post of clerk of works to the South Shields Corporation and remained there until 1897 when he became contract engineer to Messrs. W. T. Glover and Co. In 1900 he left for Australia in connection with the laying of the first underground cables for the Electric Light and Traction Co., Melbourne. Subsequently he entered the service of the Sydney Municipal Council, in which he occupied the position of chief electrical engineer under Mr. T. Rooke. When the Electric Light and Power Supply Corporation was formed in 1908 he was appointed chief electrical engineer. He became general manager in 1914 and managing director in 1921. He was also senior partner of the firm of Messrs. Donoghue and Carter, consulting engineers. He was one of the four experts appointed by the State Government in 1925 to inquire into the question of electricity supply covering the whole State. He was elected an Associate Member of the Institution in 1900 and a Member in 1911, and from 1916 until his death he served as Local Honorary Secretary for New South Wales.

J. N. P.

WALTER EMMOTT, who was born in 1854 and died on the 4th March, 1935, was a pioneer of telephony and electric lighting, particularly in the West Riding of Yorkshire. He spent most of his working life in Halifax and was partner with the late Edmund Blakey in the firm of Blakey, Emmott and Co. In 1880 they opened the first telephone exchange in Leeds, later taken over by the United Telephone Co., which subsequently merged into the National Telephone Co. They also constructed the first successful trunk telephone line between Leeds and Bradford. At their works in Square Road, Halifax, dynamos and instruments were made in the 'eighties and until 1894, when Mr. Emmott started on his own account as a consulting electrical engineer. He was a principal promoter of the Halifax Electric Light and Power Co., which built and equipped the first electricity undertaking. Another subsidiary which he helped to found, and of which he was a director, was the Northern Electric Wire and Cable Manufacturing Co. As a consulting engineer he was retained by a number of municipalities and urban district councils in Yorkshire; he also carried out the electrification of many factories in the North of England. He took a prominent part in the formation of the Leeds Local Section (now the North Midland Centre) of the Institution, and was chairman in 1904–5. When in his seventies he helped to found, and was the first president of, the Halifax Wireless Club. He was also a life member of the Halifax Scientific Society. He was a prominent Freemason and was given a Masonic funeral. He joined the Institution as an Associate in 1878, and became a Member in 1886.

E. K. S.

SIR ALFRED EWING, K.C.B., LL.D., F.R.S., was born on the 27th March, 1855, and died on the 7th January, 1935. He was distinguished by the varied nature of his services to his country. To the electrical engineer his discovery—rediscovery he called it—of magnetic hysteresis and all that it involves is the most important, and its story is an interesting one. A distinguished student of the University of Edinburgh, he had assisted Prof. Fleeming Jenkin in various researches. In his vacations he had been on cable-laying expeditions for Sir William Thomson and Jenkin. As a boy he had read an article in *Good Words* (1865) by Thomson and Tait on "Energy," explaining the doctrine of the conservation of energy, and, from that time on, Thomson was his leader. In 1878, when 23 years old, he accepted, on Jenkin's nomination, the professorship of engineering in the University of Tokio. The appointment was for 3 years, afterwards extended to five. His experience in Edinburgh had fostered his love of research, the desire for new knowledge, the hope of unveiling some of the mysteries of Nature. As he told the University of Cambridge later, "All engineering laboratories endeavour, as all university laboratories, to contribute to the common stock of knowledge by furnishing opportunities and appliances for original research."

And so in Tokio, with the help of students, a number of whom—Tanakadate is a striking example—became distinguished, he started research. His problem was where to begin. He was a young man in a far country. He had his urge for research, time and opportunity were there; the problem must not be too difficult, the apparatus simple. He began in continuation of some observations of Thomson 25 years previously, with experiments on the thermoelectric effects produced by stretching a wire under a varying load. He found an unexpected result.* When, after a wire had once been stretched, any given load was gradually applied and removed successively within the new elastic limit, the thermoelectric effects for equal amounts of stress during loading and unloading were widely different but passed through a cyclic series of values for each repetition of the cyclic changes of stress. His conclusion was that "the curves got by putting on load (not exceeding the elastic limit) and by taking it off, are far from coincident but form a closed curve enclosing a wide area." And again, "it is suggested that the cyclic phenomenon so conspicuous in this investigation is not peculiar to the thermoelectric effects of stress but may perhaps be found to occur in the changes of any quality of matter which is a function of another variable quality such as temperature, when the latter quality is subject to increment and decrement." In another paper† the effects of twisting a wire when under magnetization are discussed and a similar effect is described. "To this action, which is like that described by the author as a characteristic of the curves connecting thermoelectric quality with longitudinal pull . . . the author now gives the name of 'hysteresis' (*ὑστέρησις*) from *ὑστερέω*, to lag behind." A further paper‡ deals with the changes in the magnetization of iron produced by (1) change of the magnetic field, (2) change of stress, and (3) change of temperature, and in it he points out that if curves are drawn giving the relation of I, the intensity of magnetization, to H, the magnetizing force, the curves form loops whose area measures the work done per unit of volume in performing the cycle.

A detailed account of all this work is given in a paper in the *Philosophical Transactions of the Royal Society* (1885, vol. 176, part II, p. 523). His final definition of hysteresis is as follows: "When there are two qualities M and N such that cyclic variations of N cause cyclic variations of M, then if the changes of M lag behind those of N we may say that there is hysteresis in the relation of M to N." But he had been forestalled. German physicists had recognized the importance of *elastische nachwirkung*, so called by Kohlrausch in 1856, in many branches of physics, and Warburg in 1880 had published an account of the experiments in which he showed by the magnetometric method that if an iron wire is subjected to a cyclic magnetizing force, the magnetic moment of the wire will be greater when the force is increasing than it is when the force is decreasing, while, further, the integral $\int m\, dH$ measures the work done in the cycle. Warburg sent a note describing his earlier work to the *Philosophical Magazine* in February, 1883, and Ewing replied from Tokio in May, 1883, acknowledging Warburg's priority and regretting that he was unaware of his work. The whole story illustrates Ewing's own view, expressed in a reply to an Address received from the City of Edinburgh in 1929, that he possessed the faculty for grasping at the skirts of happy chance when they presented themselves. "They seemed to present themselves," he said, "oftener when I was a young man than they do to young men now, but I dare say happy chance wears her skirts like other women should now."

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* *Proceedings of the Royal Society*, 1881, vol. 32, p. 399.

† *Ibid.*, 1881, vol. 33, p. 21.

‡ *Ibid.*, 1882, vol. 34, p. 39.

One who knew him intimately wrote to the writer of this notice recently, "whatever gifts he had or hadn't for scientific work, he possessed in a marked degree that inconspicuous, but none the less valuable and rare, faculty, for seeing, taking, and holding, opportunities which come and which go if they are not grasped quickly." From his book "Magnetic Induction in Iron and other Metals" published in 1891, many have learnt all they know or need to know about the subject. Advancing years have shown the importance of his work.

Magnetism continued to interest him for many years. Some of us remember with pleasure his attempt to connect the effects he had observed with Weber's theory of magnetic molecules, and the beauty of his experiments in which a series of small compass needles arranged on a board were subject to magnetizing force and by their behaviour illustrated that theory, while in a James Forrest lecture on "Magnetism" delivered in 1899 to the Institution of Civil Engineers, starting with Hoang Ti, who, some 24 centuries before the Christian Era, is said to have piloted his junks by the aid of a piece of loadstone floated on water, he traced the story of magnetic discovery through Marco Polo and Peregrinus to Faraday, his own discoveries, and his model of Weber's magnetic molecule.

He was elected a Member of the Institution in 1893.

R. T. G.

[The writer acknowledges with thanks the permission of the Royal Society to make use of a notice of Sir Alfred Ewing published in their *Proceedings*, from which much of the above has been taken.]

JAMES SIMCOE FITZMAURICE was born in Melbourne in 1861, was educated at Christ Church and St. Phillip's Colleges in Sydney, and served his engineering apprenticeship with Morts Dock and Engineering Co., Sydney, for a period of 5½ years. He was appointed engineer in the Electric Light Branch of the New South Wales State Government in 1883, becoming chief engineer in 1891. He was in charge of the installation of electric light in the Jenolan Caves, New South Wales, in 1887, and he also installed electric light at various places in Sydney at that time, including the G.P.O. He carried out the illuminations for Queen Victoria's Jubilee, and also for the visit of the present King and Queen to Sydney in 1901. When the Federal Government took over the telegraph and telephone services of the Commonwealth in 1901, Mr. Fitzmaurice transferred to the Commonwealth Service and remained in Sydney until 1911, when he was appointed electrical engineer in the Commonwealth Service at Perth, Western Australia. In 1918 he was transferred to a similar position in Adelaide, where he remained until his retirement in 1926. He was very interested in radio work for many years, and had the only private radio set permitted in Western Australia during the War. He personally made most of the parts he used. He also invented a system of electric lighting for use on bowling greens, which has been adopted by many clubs throughout Australia, the evenness of illumination being the principal feature. He held the rank of Major in the Australian Military Forces. He was elected a Member of the Institution in 1891.

F. W. W.

FREDERICK ANDREW FITZPAYNE was born on the 23rd September, 1878, and died on the 3rd March, 1935. He was educated at All Saints, Bloxham, Devonshire, and received his technical training at Faraday House, obtaining the diploma of that institution. In 1897 he became a premium apprentice in the works of Browett Lindley and Co., Manchester, and subsequently premium apprentice in the works of the South London Electric Supply Corporation. From 1899 to 1900 he was a pupil with the borough electrical and tramways engineer at Southend-on Sea, and was there engaged on the installation of the third-rail conductor tramway. In 1900 he became an assistant on the staff of the Great Yarmouth Corporation Electricity Department, and from 1902 to 1906 he was chief assistant electrical and tramways engineer to the same Corporation. During that time he was responsible for the installation of the original tramways, and subsequently for two extensions and for the conversion of the original Gorleston horse tramways to electric traction. From 1906 to 1909 he was superintendent engineer to the Leith Corporation tramways, later becoming general manager. He held this post for 10 years, during which time there was an extension of 6 miles of single track. On the amalgamation of the Leith Corporation with the Edinburgh Corporation in 1920 he was appointed deputy general manager. The Leith tramways were made part of the Edinburgh tramways, and as at that time Edinburgh was operating a cable system the electric tramways in Leith formed the nucleus of the future electric system throughout the city. As deputy manager to the Edinburgh Corporation Tramways he was responsible to the general manager for the specification and plans for the electrification of the Edinburgh tramways from cable traction and for the putting into service of over 100 new buses where there had been no tramway facilities. In 1929 he was unanimously appointed general manager to the Edinburgh Corporation Tramways, and since then the transport receipts have been increased by over 50 per cent. He was responsible for the pioneer work in connection with the use of all-steel omnibus and tram bodies and also had built in the tramway workshops one of the few all-aluminium tramcars. This tramcar was a complete success, and subsequently a programme was commenced for building a fleet of composite tramcars in the Corporation's workshops. He was responsible also for the development of the regenerative equipment for the electric tramcar, and a fleet of cars operating on this system are now running in Edinburgh. It is interesting to note that during his managership Edinburgh operated the first motor-bus in this country to be equipped with fluid flywheel and epicyclic gear-boxes. He was elected an Associate Member of the Institution in 1913, and became a Member in 1921. E. S.

JOHN PERCIVAL FORSTER was born in Durham on the 12th October, 1887, and died at Newcastle-upon-Tyne on the 13th October, 1934. He received his early education in Durham and St. Bees, Cumberland, and subsequently matriculated at Armstrong College, Newcastle-upon-Tyne, where he had a distinguished career, graduating in 1907 with the Durham University B.Sc. degree in electrical engineering. After a short term in the works of Messrs. Scott and Mountain of Gateshead-on-Tyne, he entered the engineering offices of the North-Eastern Railway Co. at York. In 1911 he obtained an appointment with Messrs. Bolckow, Vaughan, and Co. as electrical inspector for their collieries in the Bishop Auckland area, being subsequently appointed electrical engineer and later chief engineer. During this period he was responsible for the reorganization of the extensive electrical and mechanical plant at this group of collieries. He continued to hold the last-named appointment until June, 1928, when he joined the staff of the Newcastle-upon-Tyne Electric Supply Co. (now the North-Eastern Electric Supply Co.). During the last few years of his life he was in charge of the mines department of the company, and in that capacity was responsible for the negotiation of a large number of important power contracts among the colliery companies of Northumberland and Durham. He was a man of quiet disposition, possessing a very alert mind and great powers of concentration. His strong personality was always impressive and he was highly esteemed for his ability and character by all who knew him, and especially by those with whom he had been so long associated in the mining industry. He became an Associate of the Institution in 1911, an Associate Member in 1912, and a Member in 1930. A. B. M.

WILLIAM MASTERMAN FRANCE, who died in London on the 20th July, 1934, at the age of 67, was born at Liverpool on the 27th October, 1867. He joined the electrical department of the Lancashire and Cheshire Telephone Co. in Liverpool in March, 1883, and was associated with telecommunication engineering all his life. In 1889 he was placed in charge of the erection and maintenance of telephone exchange equipment in the Liverpool District, and, on reorganization following the amalgamation with the National Telephone Co. in 1893, was appointed chief electrician of the same District. In the following year he was transferred to the Engineer-in-Chief's staff, but with headquarters at Liverpool, and for 5 years he was engaged in testing cable apparatus and materials at contractors' works. In 1899 he came to headquarters in London and was engaged in design and development work in connection with the provision of new telephone exchange plant, particularly in London and other large cities in the National Telephone Co.'s network. During these early days the work was largely of a pioneer character. Manual systems on a C.B. basis were rapidly replacing the former comparatively simple magneto systems. This work was of great importance to the telephone company and was carried out with conspicuous success by Mr. France. He remained in this position, both under the National Telephone Co. and after transfer to the Post Office, until 1917, when he was transferred to work in the field in the Nottingham District for two years, returning to London in 1919 to his former work in connection with the building of new exchanges. He retired from the service in October, 1928. He was closely associated with the arbitration proceedings in connection with the purchase of the Telephone Co.'s plant by the Post Office. He was a prominent Freemason and took special interest in the Telephone Lodge, of which he was a founder in 1908. His prevailing characteristics were sound judgment, thoroughness, and modesty, and he was always anxious to give credit to those working under him. He joined the Institution as an Associate Member in 1900 and was elected a Member in 1921. I. H. J.

WILLIAM PUDDICOMBE GRANVILLE died on the 26th June, 1935, at the age of 80. He entered the service of the Telegraph Construction and Maintenance Co. in September, 1869. During the earlier years of his service with this company he took part in the laying of many of the cables manufactured by them, including those to India, Australia, and across the Atlantic to Newfoundland. Later he became an assistant to Mr. Willoughby Smith, Senior, in his experimental work and training school for cable electricians. Shortly after the latter's retirement from the management of the Gutta Percha Works of the T.C. and M. Co. at Wharf Road, he became assistant manager to the present Mr. Willoughby Smith who had followed his father in the position of manager. Mr. Granville eventually became manager of the Gutta Percha Works, a position from which he retired in 1924. Unable, through ill-health and advancing years, to take as active an interest in electrical matters as he had done in the past, he spent much time on radiotherapy and there are many who will remember with gratitude the benefit they derived from his help. This latter work was typical of the man who, throughout his life, had always been so willing to help those around him, and the fact that in his retirement he was still able to help others brought much pleasure to his last years. He was elected an Associate of the Institution in 1873 and a Member in 1889. H. C. C.

JOHN GRAY, B.Sc.(Eng.), was born on the 17th April, 1874, and died on the 12th March, 1935. He was educated at George Watson's College, Edinburgh, and received his engineering training at the Glasgow and West of Scotland Technical College and Glasgow University, where he took his B.Sc. degree in engineering in 1894. From 1891 to 1893 he received practical training in the works of Messrs. Kelvin and White. In 1894 he became the private assistant and secretary to Lord Kelvin, carrying out experimental research work in the laboratory and dealing with Lord Kelvin's correspondence, etc. In 1898 he joined the firm of Messrs. Marks and Clerk, consulting engineers and patent agents, first as a pupil and later as a member of the technical staff and manager of the Manchester office of the firm. In 1902 he took the position of technical adviser and patent expert to the British Thomson-Houston Co., and became a director of the company in 1927. When the British Broadcasting Co. was formed in 1922 Mr. Gray was one of the directors. He was elected an Associate of the Institution in 1896, an Associate Member in 1902, and a Member in 1913.

JAMES HARRINGTON was born on the 2nd March, 1875, and died on the 18th February, 1935. He was educated at Hampden Gurney School and Marylebone Grammar School. He received his technical education from 1889 to 1896 at the Finsbury Technical College and with Messrs. Storey and Co., to whom he was apprenticed. In 1896 he joined the firm of Ferranti, Ltd., as an assistant. He held this post until 1898, when he became principal assistant and works manager to the Edison and Swan United Electric Light Co. From 1905 to 1908 he held the position of works manager in the Sir Hiram Maxim Electrical Engineering Co. In 1908 he became managing director of Messrs. Hill and Harrington, electrical engineers and contractors, remaining in this position until 1921. In the following year he became a consulting engineer, in which capacity he was responsible for the electrical equipment of many country houses, farm estates, boarding schools, and factories. He was elected an Associate Member of the Institution in 1917 and a Member in 1927.

ARTHUR FREDERICK HARRIS, who died at his home in Sidcup on the 8th December, 1934, was born on the 27th January, 1874. He was educated at Brixton Grammar School, New College, Eastbourne, and the Central Technical College, and was in business during his earlier years with Robert Paul, who was engaged at that time in the development of the first cinematograph projectors. In 1899 he joined the firm of Messrs Nalder Brothers and Thompson, becoming a director in 1904 and managing director in 1930. At the time of his death he held the positions of managing director and chairman. In addition to the work of his own firm in which he was always actively engaged, he took a keen interest in the British Electrical and Allied Manufacturers' Association, both as a member of the Council and, from time to time, of various technical and advisory committees. He was elected a Student of the Institution in 1892, an Associate in 1895, an Associate Member in 1903, and a Member in 1929. A. G. O'N.

JAMES FLEMING HERD was born on the 30th July, 1888, and died on the 22nd July, 1935. He was educated at the Harris Academy, Dundee, and from 1910 to 1916 he received engineering training at Dundee Technical College and with the Dundee G.P.O. telegraph service. During the latter part of the War he was a technical instructor in the Royal Flying Corps wireless school at Farnborough, later becoming officer instructor in the Royal Air Force electrical and wireless school. From 1920 to 1921 he held the position of senior professional assistant in the Meteorological Office, Farnborough, where he was engaged in the investigation of atmospherics. In 1921 he became assistant and deputy to the Superintendent, Radio Research Station (Department of Scientific and Industrial Research), and was engaged in the investigation of atmospherics, direction-finding, propagation of waves, etc. In 1933 he was promoted to the position of senior scientific officer in charge of the Radio Research Station at Slough. He was awarded a Wireless Section Premium of the Institution in 1926 as the joint author of a paper on "An Instantaneous Direct-Reading Radiogoniometer." He was also joint author of a monograph on "Applications of the Cathode-Ray Oscillograph in Radio Research." He was elected a Graduate of the Institution in 1919, an Associate Member in 1924, and a Member in 1934. R. A. W. W.

JOHN HENRY HOLMES, who was elected a Member of the Institution in 1892, was born on the 6th June, 1857, and died on the 27th April, 1935. His death severed one of the few remaining links with the early days of our profession and industry, when an electrical engineer had to be rather a universalist than a specialist. It is true that the range of subjects was less than now; but knowledge was also restricted. Much of the procedure was by rule of thumb, and anything that threw light on methods of predicting results was hailed as truly epoch-making.

Some of his school-years were spent at the Friends School at Bootham, York, where the rudiments of science were included in the ordinary course, and where he also had leisure-time opportunities of gaining experience in the use of tools. At the age of 16 he went with an entrance exhibition to the Durham College of Science (now Armstrong College), where the only professors were those of mathematics, geology, physics, and chemistry; and two years later he was apprenticed to Head Wrightson and Co., of Stockton-on-Tees. There he began to handle electrical apparatus: an arc light was installed in the Bridge Yard, and the dynamo to work it was Siemens and Halske's No. 61. In August, 1881, after time spent in various capacities with John Abbot and Co., of Gateshead, Thomas and Charles Hawksley, of Westminster, and Clarke Chapman and Gurney, of Gateshead, Mr. Holmes entered the service of Mr. John S. Raworth, of Manchester, and so became an electrical engineer. His duties began with a share in the lighting of the new ship *City of Rome* with 16 arc lamps and 230 Swan lamps, and continued in many other installations, both in ships and ashore, until April, 1883, when he left Mr. Raworth and, in partnership with his father and two elder brothers, established an electrical engineering business in Newcastle-on-Tyne under the name of J. H. Holmes and Co.

The undertaking so founded went on as a partnership for 45 years until 1928, after which the established goodwill and traditions of the firm were continued by A. Reyrolle and Co., Ltd., under the style of J. H. Holmes and Co., Ltd., so that at the time of Mr. Holmes's death the work he initiated had gone on for over half a century, under his own care for most of the time, and even now it has not ceased.

The first Holmes dynamo was built in 1884, and in the same year Mr. Holmes invented the quick break switch. In 1889 he visited Egypt to study the requirements of vessels passing through the Suez Canal by night, and afterwards designed and supplied portable lighting apparatus that effectively increased the capacity of the Canal by greatly extending its use in the dark hours. Train-lighting and electroplating dynamos were also produced; and in 1897 the commencement of the sale of "Lundell" motors, under patent rights from America, was a pioneering step in the application of electric driving in industry. One of the interesting uses of these motors in 1897 was for the propulsion of electric cabs. In 1898 the patented Holmes–Clatworthy 2-motor system of driving newspaper-presses was introduced, and many of the world's most important newspapers have been printed by its agency. The firm continued to develop as general manufacturing electrical engineers, and Mr. Holmes's personal influence on its engineering side was invaluable because of his almost passionate love of good mechanical ideas. His friends who used to see him in his workshop (now transferred practically intact to the Newcastle-on-Tyne Municipal Museum of Science and Industry) will need no further reminder of his fine workmanship.

Those who knew John Henry Holmes personally will remember him as a man of a rather retiring nature. He had a heart that prompted him to many kindly acts and caused him to take a particularly keen interest in young people, and his orderly mind compelled him to do his best in all that he undertook and enabled him to play a notable part in the spread of a new way of doing things.

T. C.

WILFRED HOLMES was born in 1878 at Ashton-under-Lyne, where he received his early education and training as a mechanical engineer. He then studied electrotechnics at the Manchester College of Technology, where he was awarded the King's Prize. He continued his electrical studies at Owens College, Manchester (now the Manchester University). In 1903 he joined the staff of Ferranti, Ltd., as a technical assistant in the meter department, and became the trusted assistant and friend of the late Dr. S. Z. de Ferranti, under whom he did invaluable work in the realm of instruments, meters, and kindred apparatus, and as chief engineer and manager of the meter and instrument department was responsible for the design and manufacture of all instruments, relays, special metering gear, electric clocks, and small synchronous motors. He was an accepted authority on metering problems and made contributions on these subjects in the technical Press and in the *Journal.* He was elected Associate Member of the Institution in 1928 and a member in 1932, and was one of the foundation members of the Meter and Instrument Section. He read a paper before the Institution on "Load-Levelling Relays and their Application in connection with Future Metering Problems," and, in co-operation with Mr. E. Grundy, one before the Meter and Instrument Section on "Small Self-starting Synchronous Time Motors." At the time of his death he was chairman-elect of the Section, and it is a great loss to the Section and to the Institution that he was not able to fill the chair. He was a man of considerable personal charm, quiet, unassuming, and yet with a knowledge and understanding of human nature which made him a friend of all who came in contact with him. His application to detail and the patience with which he applied himself to numerous problems were rewarded in the many brilliant and useful contributions he made to meter and instrument technics. He died on the 28th September, 1935.

F. C. K.

HARRY ROBERT KEMPE died at Brockham, Surrey, on the 10th April, 1935. He was born on the 1st March, 1852, at St. James's Rectory, Piccadilly. After being educated at Westminster School and King's College, he was articled to Sir Samuel Canning, engineer-in-chief to the Telegraph Construction and Maintenance Co. Then he went to Sir Charles Wheatstone and to Robert Sabine. In 1871 he was taken into the postal telegraph service at Southampton by Mr. (afterwards Sir) William Preece and, when the latter became electrician to the Postmaster General, came with him to London.

Kempe was a man of outstanding ability in many ways. He was a mathematical electrician when Ohm's Law represented the mathematical limitations of most electrical men. His "Handbook of Electrical Testing" was somewhat of a pioneer work of its kind, with the desirable characteristic that it was not too much above the heads of those for whom it was intended. He was a thinker with a turn for practical work. One might, for instance, fairly claim that more than 50 years ago he anticipated the delayed and cumulative signal by condensers, which is the basis of our present-day traffic signals. He also had a very wise knowledge of mechanical dodges and was himself an exceedingly original mechanician.

In 1890, when the conditions for telephonic communication were very restricted, he was given the problem of designing a cable circuit between London and Paris, involving the first submarine telephone cable ever made. That submarine cable was an unqualified success; indeed, the two circuits (it was a 4-wire cable) more than fulfilled the most sanguine expectations and were superior in volume, articulation, and absence of inductive disturbance, to most of the London telephone-exchange circuits of those days.

In 1871, when the Institution was founded as the Society of Telegraph Engineers, he was one of its first members. It is noteworthy that at the age of 20 (in 1872) he assisted in founding the *Telegraphic Journal* (which later became the *Electrical Review*), and that its most important feature was a series of articles on technical telegraphy from his pen.

Besides his "Handbook of Electrical Testing" (which had a world-wide circulation and was translated into several foreign languages) he published "The Electrical

Engineer's Pocket-Book," in 1890; a handbook on "Alternating Currents," in 1916; and "The Engineer's Year-Book," which first appeared in 1894 and which, in collaboration with Mr. W. Hanneford Smith, he continued to control for 36 years.

In private and social life he was an attractive personality. Rather reserved and shunning the limelight, he was yet the most companionable of men. Apart from his many interests in his profession, the Parish Church of Brockham was his real "hobby" from the time when, as a young married man, he cleaned and decorated its walls until the time (and after) when his old Post Office friends combined with the people of the village to effect great improvements in the Church as a tribute of their admiration and gratitude for a great life, greatly lived. A. J. S.

WILLIAM McLELLAN, C.B.E., was born on the 7th December, 1874, at Palnackie, Kirkcudbrightshire, and died at Orchard Knowes, near Dalbeattie, on the 11th December, 1934. He was educated at Birkenhead College and Liverpool University. He interrupted his university course to obtain practical experience at the engineering works of Cochran and Co. of Birkenhead, returning to the university for a final year.

On leaving the university in 1896 his first step was to become an assistant with Messrs. Siemens Brothers and Co. He remained with them until February, 1898, when he left to join the staff of the Cork Electric Tramways and Lighting Co. as mains engineer. In Cork he began his long association with Mr. C. H. Merz, then engineer and manager of the Cork Co., which lasted for the rest of his life.

In December, 1899, he resigned his position at Cork and went to Tyneside, where, in association with Mr. Merz, he took a prominent part in the development of the electric power undertaking of the Walker and Wallsend Gas Co., including the design of the Neptune Bank power station, which was, a little later, the first large power station in Great Britain to use steam turbines. In 1902 the electric part of the Gas Company's undertaking was taken over by the Newcastle-upon-Tyne Electric Supply Co. (now the North-Eastern Electric Supply Co.), the pioneer power company in Great Britain. It was then that the firm of Merz and McLellan was formed, and the firm has since that time acted as consulting engineers to the North-Eastern Electric Supply Co.

In 1903, in conjunction with Mr. Merz, he contributed a paper on "Power Station Design" to the *Journal* of the Institution, and thereafter a great part of his time was occupied in power-station construction. He was responsible for much of his firm's work of this kind at home and abroad. He travelled to America, Australia, India, and Argentina. This last journey was in connection with the electrification of the Central Argentine and Buenos Aires Western Railways, and he was in fact on his way home from Buenos Aires in August, 1914, at the outbreak of war. He at once joined the 17th Battalion of the Northumberland Fusiliers as a second lieutenant. Applying himself to his military duties with characteristic thoroughness, he was quickly promoted, and would no doubt have accompanied his battalion to France in the late summer of 1915 had he not received a call, impossible of refusal, from Sir Eric Geddes, then newly appointed Director of Production in the Ministry of Munitions, to assist in the urgent task of providing an adequate supply of power for munition work. For 2 years he held this position, which later became that of Director of Electric Power Supply. During this time he was made Lieut.-Colonel and paid visits to Palestine, Egypt, and several to France in connection with technical and transport problems. When the submarine menace became acute he went to the Admiralty with Sir Eric Geddes, the latter having been appointed First Lord, and took a prominent part in helping to overcome it. In 1918 he accompanied two diplomatic naval missions; the first to the United States of America, the second to Italy. For war services of unusual interest and variety he was made C.B.E. in 1919.

After the War he resumed practice as a consulting engineer. This was a period of reconstruction in the electricity supply industry. Meantime the growing demand for electricity in the London area, particularly for power purposes, had to be met by the construction of the Barking power station. To the design of this station, as to that of the new Dunston station on the Tyne, he gave a large part of his time during early post-War years. The chief preoccupation of his later years was the creation and direction of the Galloway Water Power Co.

His personal characteristics were simplicity and directness. Preferring, as he always said, to arrive at his conclusions from first principles, he had the ability to go to the heart of an engineering problem. His conclusions were sound and had rarely to be reconsidered. Though in his later years he became reluctant to attend a function of any kind, public or private, up to and beyond the war years he sought companionship and he will be best remembered by his friends as a sympathetic companion, willing to share all he possessed in thought and kind. Most of his friends were also his contemporaries, and amongst these he has left a gap impossible to fill. The steam-power-stations he designed will be replaced in the due course of development, but the Galloway water power scheme is likely to remain an enduring memorial in his native county of his vision and achievement as an engineer. Apart from his work his interest was in literature. His chief recreation was sailing.

He joined the Institution in 1902 as an Associate Member and was elected a Member in 1909. R. N.

ROBERT STAFFORD McLEOD died on the 22nd September, 1935, at his home in Bromley, Kent, where he had been living in retirement since 1927. After a technical course at Leicester, he served 2 years of his apprenticeship with Messrs. Gimson of Leicester and then joined the electrical department of Messrs. Mather and Platt, with whom he served the remainder of his apprenticeship. Whilst with that firm he was associated with Mr. A. P. Wood, and when the Lancashire Dynamo and Motor Co. commenced operations in 1900 with Mr. Wood as general manager, Mr. McLeod became chief engineer to the new company and retained that office for the rest of his working life. For 10 years previous to his retirement he was also a director of the company. In 1900 the enclosed type of electric motor and multipolar generators were new developments. Mr. McLeod's technical ability was shown by the success of the dynamo-electric machinery he designed for the Lancashire Dynamo and Motor Co. The Turnbull–McLeod automatic reversible booster, the Lancashire planer gear, and the Maxtorq motor were developed by him, or under his supervision, and he also did a good deal of successful work in the development of the self-starting synchronous motor. He was elected an Associate Member of the Institution in 1904 and a Member in 1913. He served on the B.E.A.M.A. Standards Committee until 1927, and was a member of the Manchester section of the Anti-Submarine Committee during the War.

He was a born engineer, with a strain of the artist, free from academic bonds, and always with an original approach to the problems of his time. His unassuming manner, his kindly spirit, and his humorous attitude to life in general, will long be remembered by his old colleagues and friends. J. H. W.

WILLIAM HENRY UPTON MARSHALL, who died at Southsea on the 14th January, 1935, was born on the 30th September, 1870. He was educated at the North London Collegiate School, Camden Town, and St. Mark's College, Chelsea. On leaving school he entered the office at Westminster of Mr. W. Perrott, civil engineer, and subsequently obtained practical experience with a firm of mechanical engineers, continuing his training at King's College and University College, London. After some years' experience as a draughtsman with various firms, he joined Messrs. Preece and Cardew. Whilst with the latter firm he was employed as resident engineer on the electrification of H.M. Dockyard, Portsmouth, and Haslar Hospital.

A few years prior to 1914 he joined the Royal Engineers Volunteers, obtaining a commission. During the War he became a captain in the Territorial Army, and was engaged on various Government electrical work in the Southern Command. After demobilization he started as a consulting engineer at Southsea. He acted as an inspector and assessor to the Automobile Association, and also for a large number of insurance companies in connection with motor vehicle work, and was a director of several cinematograph companies.

He joined the Institution in 1906 as an Associate Member, becoming a Member in 1909. A. G. H.

FREDERICK LATOUR MILNE was born on the 14th March, 1881, and died on the 31st January, 1935. After being educated in India and at United Westminster School, London, he went for 2 years as a premium apprentice to Messrs. J. W. F. Andrews and Co. at their Fulham works. He then took a 2-year course at Finsbury Technical College. On leaving the college in July, 1902, he was engaged for 6 months in the cable-testing department of the Western Electric Co. at Woolwich, but shortly afterwards resigned on obtaining an appointment with the Mysore State Government as shift engineer on their Cauvery hydro-electric power scheme. He was later engaged on the construction of the Bangalore power station and became assistant to the chief engineer. From 1908 to 1910 he was engaged by the Raub Australian Gold-Mining Co., first as assistant engineer and subsequently as chief engineer of the hydro-electric plant at Penang, F.M.S. He was then for a short time in the employ of Messrs. Geyer and Co. on the construction of the Simla hydro-electric works and transmission lines, being later appointed resident engineer by the Punjab Government, in which capacity he supervised the completion of the scheme in 1913. Subsequently he was appointed chief electrical engineer by the Simla Municipality and held that position until 1921 when he became electrical engineer to the Punjab Government. In that capacity he was responsible for the provision of electricity supply to a number of towns in the Punjab, and before his death he had the additional responsibility of chief electrical inspector. He was elected an Associate Member of the Institution in 1907 and a Member in 1920.

DAVID KING MORRIS, Ph.D., younger son of James Morris, M.D., was born on the 5th January, 1874, and died on the 14th May, 1935. He was privately educated and entered University College, London, in 1891, where he studied mechanical and electrical engineering and physics under Professors T. Hudson Beare, J. A. Fleming, and G. Carey Foster. He showed aptitude for research, assisting Prof. Fleming (now Sir Ambrose Fleming) in electrical investigations. Elected as an 1851 Exhibition Scholar in 1894, he worked at University College with Prof. A. W. Porter on dielectric and magnetic hysteresis, and later under Prof. Weber at Zurich. In 1897 he obtained the degree of Ph.D. for a thesis on "The Magnetic Properties and Electrical Resistance of Iron as Dependent on Temperature." Returning to England he was elected Fellow of University College, London, at the age of 24. After one year as senior demonstrator in electrical engineering at Chelsea Polytechnic, he was appointed lecturer in electrical engineering at Mason University College, Birmingham. He was there responsible for the entire work of the Electrical Engineering Department, and for much research carried out, or inspired, by him.

After 1900, when the University of Birmingham was greatly extended, he drew up the original plans for the Electrical Engineering Section of the new University, and designed the equipment of the laboratories, admittedly then amongst the finest in the country. After the appointment of Prof. Gisbert Kapp to the Chair of Electrical Engineering at Birmingham, Dr. Morris with his assistant, Mr. G. A. Lister, left, and started the business of Messrs. Morris and Lister. In 1914, supplies from Germany having ceased, this firm supplied ignition apparatus to private firms and to the Mechanical Transport Department of the War Office. In 1915, the M-L Magneto Syndicate, Ltd., was formed to develop the production of aircraft magnetos for the Royal Naval Air Service. During the War Dr. Morris did other work of national importance; this included an early investigation into the problems of the detection of submarines, which finally resulted in the Sykes–Morris directional hydrophone.

After the War the M-L Magneto Syndicate, Ltd., extended their activities, notably in connection with rotary transformers and apparatus for radio purposes, and in the development of these Dr. Morris took a leading part. He was largely responsible for the formation, in 1915, of an association of British magneto manufacturers. Latterly his health compelled him to give up regular work, and after the magneto business was acquired by Messrs. Joseph Lucas in 1930, he confined himself to consulting and patent work for them and for Messrs. S. Smith and Sons (M.A.).

He joined the Institution as a Student in 1892, was elected an Associate Member in 1899 and a Member in 1907, and served as Honorary Secretary of the Birmingham Local Section (now South Midland Centre) from 1900 to 1906. Of a retiring disposition, and increasingly suffering from asthma, Dr. Morris was known to few of his profession, yet he contributed several papers to the Institution, including papers on the uses of the oscillograph and on the design of eddy-current brakes for motor testing. E. A. W.

EDWYN LONSDALE POPE was born in 1868 and was educated privately. He served his time under the late Mr. Frank King with the Electrical Power Storage Co. at Millwall, being engaged on the installation of batteries and switchgear in the substations and power station of the Chelsea Electric Supply Co. at Draycott-place. On completion of the installation he transferred to the Chelsea Co. as assistant engineer. After some years there, he became one of the outdoor engineers to Callender's Cable and Construction Co., with whom he remained until 1902, when, having installed a large proportion of the distribution cables in connection with the initial sections of the London County Council tramways on behalf of his firm, he was appointed assistant to Mr. J. H. Rider, chief engineer of the tramways. He remained with the L.C.C. as distribution engineer until June, 1919, when he was compelled to retire owing to ill-health. After his retirement he lived quietly at Holt, Norfolk, where he was interested in dogs and where he died on the 3rd June, 1935. He was elected an Associate of the Institution in 1892, an Associate Member in 1902, and a Member in 1912.

SIR PERCY JOHN PYBUS, Bt., C.B.E., who died on the 23rd October, 1935, at the age of 55, received his training at the Hull Technical College and as an apprentice at Messrs. Priestman Brothers of Hull. From 1898 to 1900 he was employed as a draughtsman by that firm, after which he was for a short time with Messrs. Siemens Brothers in their Design Department and in the Estimating Department of Messrs. Siemens Brothers Dynamo Works at Stafford. From 1902 to 1907 he served as assistant to the works manager of the latter firm. In 1907 he was appointed works superintendent of the Phoenix Dynamo Manufacturing Co. In this capacity he re-organized the works and subsequently, in 1910, was appointed general manager and managing director. He later became managing director of the English Electric Co. and was chairman until 1927, retiring from the Board of that Company in 1931.

In 1929 he entered Parliament as the member for the Harwich Division of Essex, and in 1931 was appointed Minister of Transport in the National Government. This necessitated his giving up many of his business interests in order to devote his time more fully to the piloting of the London Transport Passenger Bill through the House of Commons. He resigned from the Government in 1933, as he did not desire to devote his whole attention to politics, but he remained a Member of Parliament up to the time of his death.

He served on a number of commissions and committees, including the Royal Commission on the Civil Service, the Committee on the Classification and Definition of Firearms, the Development (Public Utility) Advisory Committee, the Committee on Education for Salesmanship, and the Unemployment Grants Committee. He was created a C.B.E. in 1917, and a baronetcy was conferred upon him in 1934. At the time of his death he was chairman of the Phoenix Assurance Co., and a director of the " Times " Publishing Co., the Associated Portland Cement Manufacturers, the British Portland Cement Manufacturers, the London Guarantee and Accident Co., and Metal Traders, Ltd.

He joined the Institution in 1910 as an Associate Member and was elected a Member in 1911. C. R.

MAJOR-GENERAL SIR RICHARD MATTHEWS RUCK, K.B.E., C.B., C.M.G., R.E., who was born on the 27th May, 1851, died in London on the 18th March, 1935. Educated at a private school and at the Royal Military Academy, Woolwich, he joined the Royal Engineers in 1871, and after completing his course at the School of Military Engineering, Chatham, entered the submarine mining service in 1874. In 1881 he was appointed assistant instructor at the School of Military Engineering. Transferred to the War Office in 1885, he was the following year appointed an assistant inspector of submarine defences, and in 1891 was promoted to the position of inspector. He left the War Office in 1896 on being raised to the rank of lieut.-colonel, and shortly afterwards went to Malta as commanding officer, Royal Engineers, West Sub-District. He was recalled to the War Office in 1902 to take up the appointment of deputy inspector-general of fortifications, and in 1904 he became director of fortifications and works. In 1908 he went to the Eastern Command as major-general in charge of administration. Although he had retired from the Army in 1912, on the outbreak of the War he volunteered for service, and was appointed chief engineer to the Central Force. Later he became vice-chairman of the Air Inventions Committee and a member of the Civil Aerial Transport Committee. He was elected a Member of the Institution in 1896.

CHARLES NEWTON RUSSELL, who died on the 22nd December, 1934, was one of the pioneers of the electricity supply industry in the London area and his name will always be linked with those of the engineers who, in those now far-off days, laid the foundations of what has since become one of the largest and most important industries in the country. To mention a few: such names as Hammond, Arthur Wright, Ferranti, Kennedy, Frank Bailey, Sidney Baynes, and Albert Gay, leap to one's memory. Newton Russell was a contemporary of these men and his pioneer work deserves to be remembered along with theirs.

He was born in 1859 and served his apprenticeship at Stockton-on-Tees. He afterwards took up the study of electricity, in the pursuit of which he visited several large electricity works in the United States. He also studied at the School of Telegraphy and Electrical Engineering, Hanover Square. In 1882 he took up a post with the firm of W. T. Gooden and Co. and had charge of their section of the lighting of the Inventions and other Exhibitions at South Kensington, as well as the carrying out of a large amount of important work for the British Admiralty. In 1887 he secured an appointment as engineer to the Acton-Hill Electrical Works, his next move being in 1892 to the post of manager to the London and Lancashire Electrical Co., Dalston. He was subsequently appointed in 1897 by the Shoreditch Vestry as chief officer of the electricity undertaking, a post which he held continuously until December, 1925, when, having reached the age limit, he relinquished the position of borough electrical engineer, remaining in a consulting capacity until December, 1926, when he finally retired.

In addition to his deserved reputation as a pioneer in electricity supply he was an authority on the disposal of refuse. In 1904 he read a paper before the Institution of Mechanical Engineers on "Refuse Destruction by Burning and the Utilization of Heat Generated," and in 1925 he presented to his Council a report on the subject which even to-day is looked upon as one of the most authoritative treatises on the subject. He also claimed to be the first to introduce the steel conduit for wiring purposes, and he held certain patents in connection therewith.

He was a member of a special Committee which was set up in 1909 jointly by the London electric lighting companies and the municipalities to investigate and report on the question of the future of electricity supply in the London area. This Committee consisted of Mr. C. Newton Russell, Mr. C. P. Sparks, Mr. Frank Bailey, and the writer of this notice, and it made a valuable report in June, 1910, which had a considerable influence on subsequent legislation. Mr. Russell took no mean part in the work of that Committee. He also took an active part in the work of the British Standards Institution, being a member of a number of its Panels. He was a member of the Associated Municipal Electrical Engineers, being their President in 1908, and he took a considerable part in the work of the I.M.E.A. He was elected an Associate of the Institution in 1888, and a Member in 1903.

By those who had the privilege of his friendship he was greatly loved, he had a wonderful sense of humour, and many were the amusing tales he would recount of his early pioneer experiences. W. C. P. T.

[The writer is indebted for some of the above facts to the *Shoreditch Observer* and to the kind assistance of Mrs. Russell and Mr. H. Noel Russell.]

SIR ARTHUR SCHUSTER, LL.D., Ph.D., Sc.D., F.R.S., died on the 14th October, 1934. Few men can have done more for science in this country than he did. As professor, first of applied mathematics and then of physics, at Manchester from 1881 to 1907, he taught many students who subsequently filled important posts in industrial and academic life; as secretary to the Royal Society from 1912 to 1919 he devoted his unusual administrative abilities to the organization of science in the British Isles at a difficult period in our history; and as secretary to the International Research Council he was the chief driving-force in restoring international co-operation in science after the War. He was one of those rare men who possess both scientific and business ability to an outstanding degree, and, as his sense of public service was very strong, he served on innumerable committees and governing bodies where both science and administration were required.

He was born in Frankfort-on-Main in 1851 and in 1869 came with his parents to Manchester, where he studied under Balfour Stewart and Roscoe in the Owens College and then completed his scientific education in Germany, taking his Ph.D. degree at Heidelberg in 1873. His scientific work was mainly done in the period 1876 to 1910, and included collaboration with Lord Rayleigh in his classical determination of the value of the ohm in absolute units. In early life his chief interest was in spectrum analysis, and when he took up his duties at Manchester he started intense research on the spectrum of gases electrically excited in vacuum tubes. This led him to investigate the passage of electricity through rarefied gases. He was soon convinced that the mechanism was similar to that of the conduction of electricity through electrolytes. He showed that the charge was carried by a few of the molecules "dissociated" into ions and that after ions had been formed the gas remained conducting for an appreciable period. He was the first to demonstrate that cathode rays are the tracks of negatively charged particles driven away from the cathode. He showed how the bending of cathode rays in a magnetic field could be used to measure e/m. He made preliminary measurements of this ratio but was unable to interpret his results; so that it remained for Sir Joseph Thomson to repeat the experiments later and discover the electron.

During the latter half of the nineteenth century physics was not so specialized as it is now, and Schuster's scientific work embraced many different branches of physics. He wrote largely on optics, terrestrial magnetism, and solar physics. He invented the mathematical device called the "periodogram" for detecting the presence of periodicities in series of data and for determining their reality. He took a great interest in meteorology and for 32 years served on the Meteorological Committee, the advisory body of the Meteorological Office.

He was a very generous man, not only of his own time and personal service but also of money: he gave large sums to the Royal Society and established readerships in meteorology and mathematical physics in the universities of Cambridge and Manchester respectively. He was knighted in 1920 and also received many other honours, amongst them a Royal Medal, a Rumford Medal, and in 1931 the Copley Medal, the highest honour the Royal Society have to bestow. He was elected a Member of the Institution in 1889.

RICHARD HENRY SCOTSON, borough electrical engineer of Middlesbrough, died at Middlesbrough on the 18th December, 1934, at the age of 55, owing to heart failure. His sudden demise, at this comparatively early age, was keenly felt by his large circle of friends on Tees-side, and his kindly presence will be very greatly missed by all who knew him.

He received his education at the Middlesbrough High School, and at the Durham College of Science (now Armstrong College, Durham University). He was apprenticed successively to Messrs. Baker Brothers and Messrs. Bland Brothers, both electrical contractors in Middlesbrough. On the completion of this training, in 1901, he obtained the position of mains engineer in the Middlesbrough Corporation Electricity Department, and it was while holding this appointment that he became associated with the late Mr. H. M. Taylor, then borough electrical engineer, which association subsequently led to the invention of the well-known Taylor–Scotson voltage regulator. In 1915, he became borough electrical engineer in succession to Mr. Taylor, and in this capacity he continued to serve the Corporation until his death. He took an active part in the electrical and social activities of Tees-side, and was the inaugurator of an Annual Electrical Industries Ball, by which means considerable sums were annually raised for the benefit of electrical charities.

He was elected a Member of the Institution in 1922.

W. A. G.

JAMES SCOTT, ex-mayor of Bootle, an alderman and a J.P., died on the 6th February, 1935. Born in November, 1881, he received his technical training at Booth Technical College and at Liverpool University. After serving an apprenticeship at the Booth Electricity Works and with Messrs. Campbell and Isherwood, he became in 1903 works manager of that firm, being appointed a year later managing director of Messrs. James Scott, general electrical contractors. An enthusiastic Conservative, he was a member of the Bootle Electricity Committee when Bootle had its own electricity undertaking. He was also an ex-chairman of the Highways Committee and chairman of the Parliamentary Committee until his election as mayor in 1932. Other bodies on which he served were the Liverpool Electricity Committee, the Clarence-Dock Power Station Sub-Committee, and the Liverpool Assessment Committee; he was also a land-tax and income-tax commissioner for the Prescot area, which includes Liverpool and Bootle. He acted as consulting electrical engineer to the Formby Urban Council, the West Lancashire Rural Council, and several townships in Northern Ireland, and had in hand at the time of his death two large electrical schemes in West Africa. He was intensely interested in co-operation between Bootle and other Merseyside authorities. He was a keen golfer and took a great interest in the Liverpool Centre's Golf Tournament in aid of the I.E.E. Benevolent Fund. He joined the Institution in 1894 as an Associate and was elected an Associate Member in 1913, and a Member in 1921.

O. C. W.

SIR WILLIAM SLINGO, late Engineer-in-Chief to the General Post Office, was born in 1855 and died on the 19th January, 1935, in his 80th year. After spending some months as a learner with the old Electric and International Telegraph Co., he became a telegraph clerk in the Post Office in 1870. In those days the facilities for technical education were very meagre, but with his characteristic energy and ability he applied himself to the acquisition of general scientific and engineering knowledge and, in particular, to such electrical engineering knowledge as was available at that time. He attended lectures by Tyndall, Huxley, Frankland, and Guthrie, and made full use of the South Kensington museum and library.

In 1874 he began his teaching career by opening evening technical classes in several parts of London, and in 1876 he started the "Telegraphists' School of Science" in connection with the Central Telegraph Office, London. This school started with five students but under his forceful direction it progressed so successfully that when he relinquished the post of Principal in 1898 it had 850 students. During this period he was head of the Electrical Engineering Department of the People's Palace (now Queen Mary's College of London University) and helped to develop its technical sections. He was also head of the Electrical Department of Sir Edmund Currie's residential School of Engineering at Folkestone, and consulting engineer to the Dover Corporation and to the Drapers Company, for whom he installed the steam generating plant for lighting the People's Palace and Winter Garden about 1888. He was consulted by the late Mr. Le Neve Foster during the formation of the City and Guilds of London Institute, and it was due to his influence that telegraphy became a recognized subject of tuition under the Institute at so early a date. As a result of the work of the Telegraphists' School of Science, when the Post Office launched a rapid expansion of the trunk telephone system in 1894 a large number of technically-trained qualified men in the Central Telegraph Office were immediately available for transfer to the Engineering Department to meet its pressing need.

Slingo joined the Post Office Engineering Department as a technical officer in 1898, went to Liverpool as superintending engineer in 1903, and after 8 years' experience in district work returned to London as assistant engineer-in-chief in 1911, being subsequently appointed engineer-in-chief in 1912. He was knighted in 1915, being the first engineer-in-chief to receive that honour during his tenure of office. He retired from the Post Office in 1919 after nearly 50 years' service. During his career in the Post Office Engineering Dept. he introduced many improvements and developments and was mainly responsible for the compilation of the inventory and valuation of the National Telephone Co.'s plant, taking a leading part in the arbitration proceedings relative to the acquisition of that plant by the State.

On his retirement from the Post Office he joined the Marconi Co. and acted as Administrator-General for the Peruvian Posts, Telegraphs, and Wireless Services. He completely reorganized the service and placed it on a sound basis.

He was elected a Member of the Institution in 1908, and was a Member of Council from 1916 to 1920.

In addition to his engineering and teaching activities he contributed extensively to the technical and lay Press and about 1882 was editor of *Knowledge*. In 1890, in collaboration with his assistant Mr. A. Brooker, he published a book on "Electrical Engineering," which was recognized for many years as a standard work on this subject. He was always a hard worker and expected those associated with him to apply themselves assiduously to their tasks. He was ever ready to help one in difficulty and his genial smile and keen sense of humour endeared him to his students. His old colleagues and students, many of whom attained responsible positions in the Post Office Engineering Department, will remember with love, honour, and gratitude; the passing of their master and friend. E. H. S.

CHARLES NORMAN STANILAND died on the 31st May, 1935, at the age of 63. He attended Finsbury Technical College as an evening student from 1888 to 1889, and received his practical training as a pupil first with the Bath electricity undertaking and later with Messrs. Ronald Scott, of Aston. Early in 1894 he joined the House-to-House Electric Light Supply Co. as a switchboard attendant, but left the company shortly afterwards to take charge of the work of overhauling and installing lighting installations at the Winter Gardens, Blackpool, and at Douglas, Isle of Man. After spending a short period as mains assistant at Altrincham, he was in 1895 appointed electrician in charge at the generating station of the Islington borough undertaking. In 1897 he joined the staff of Mr. Robert Hammond, under whom he was responsible for the erection and testing of generating plant. He resigned this position shortly afterwards to go to Canterbury, where he superintended the erection of the generating plant and the laying-down of the distribution system. He was appointed chief electrical engineer at Canterbury in 1899. From 1902 until his death he held the position of borough electrical engineer at Hornsey, and from 1905 was responsible for all the extensions of the undertaking. He was elected an Associate of the Institution in 1897, was transferred to Associate Membership in 1899, and became a Member in 1908. A. P. M.

JOHN EDWIN STORR, who died on the 9th May, 1935, at the age of 56, received his training with Messrs. Robey and Co. of Lincoln and at the Corporation Electricity Works at Lincoln and Croydon. He then became a constructional engineer for Callender's Cable and Construction Co. and carried out contracts for them at London and in various parts of England, and also in Germany. After a period with the Bolton Corporation, during which he was engaged on constructional work, he joined the staff of the Yorkshire Electric Power Co., with whom he remained until 1922 when he started in private practice as a consulting engineer and carried out important contracts for municipal, industrial, and private concerns. He was elected an Associate Member of the Institution in 1911 and a Member in 1927, and served as Chairman of the North Midland Centre in 1927–8.

S. R. S.

JULIUS MARTIN TIMM, for many years chief mechanical engineer of the Great Northern Telegraph Co. in the Far East, died at his home in Copenhagen on the 21st March, 1934, at the age of 76. He spent the greater part of his active life in the company's service in Shanghai, where he arrived in 1881 and where he retired in 1922 after more than 40 years of uninterrupted service in the Far East. At the time he arrived in China, the telegraph service was still in its early development there and he contributed to the organization of the company's workshop department and to the design of certain of its earlier instruments. After retiring, he lived his last years in Denmark. He joined the Institution as a Foreign Member in 1893 and became a Member in 1911.

O. E. N.

RICHARD WARING obtained his electrical engineering education in evening classes, first at the Liverpool School of Science and later at Heriot Watt College, Edinburgh, whilst serving as superintending engineer's clerk in the General Post Office. In December, 1890, he was appointed inspector, and a few months later engineer, in the G.P.O. Engineering Department at Liverpool, and in August, 1905, staff engineer in the Engineer-in-Chief's office, London. In April, 1911, he was appointed assistant superintending engineer in the London District and in July, 1918, superintending engineer in the Western District of Scotland. He died on the 31st March, 1935. He was elected an Associate Member of the Institution in 1909 and a Member in 1921.

JOSEPH STANHOPE WATSON, who was elected a Member of the Institution in 1928, was born in Gateshead on the 18th August, 1870. He was apprenticed to Messrs. Clarke, Chapman and Co., and, after a period at sea as a marine engineer, joined the Newcastle-upon-Tyne Electric Supply Co. (now the North-Eastern Electric Supply Co.). He was later appointed assistant electrical engineer to the South Shields Corporation, but rejoined in 1898 the Newcastle-upon-Tyne Electric Supply Co., with whom he remained until his death. When the electric supply industry formed their Whitley Councils in 1919–20, he was appointed chairman of the North-East Coast Area (No. 1) District Joint Board, and the North-East Area (No. 1) District Joint Industrial Council, and he retained these offices continuously. He was also a member of the Local Panel of the Court of Referees in connection with unemployment insurance. He devoted much of his leisure time to charitable work.

As a colleague, and with those who served under him, he was very popular, and he spent much time and energy in promoting the welfare of the company's staff and in the official organizations run by them. It was in the field of sport and in the personal active interest he took in all forms of sport promoted by the company's employees that he so endeared himself to them—the more particularly as he himself took part in many of the competitive events they promoted. He was thus personally known to almost all employees throughout the extensive area of the company, and was most popular and greatly esteemed by them.

His death, which occurred on the 24th November, 1934, as a result of heart failure during a game of badminton, came as a great shock to his friends and associates. All felt the sudden loss of so loyal and popular a friend.

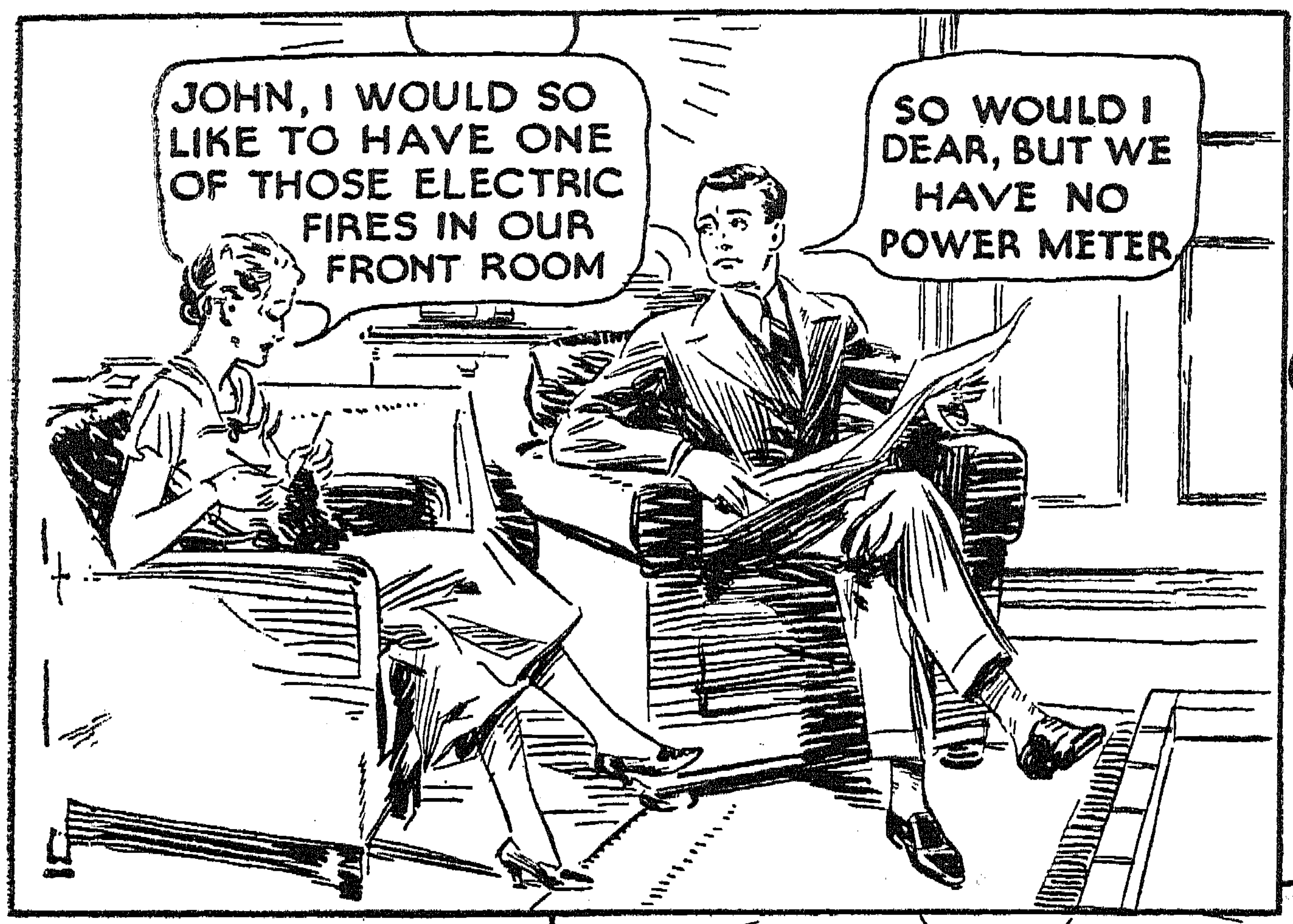
W. F. T. P.

BERNARD ROBERT WINGFIELD, Ph.D., who died on the 2nd March, 1935, in his 64th year, was born on the 13th November, 1872, at Frankfurt. He was trained as an electrical engineer, graduating Ph.D. of Rostock in 1893 and securing practical experience at the Siemens works in Berlin and subsequently with the Kummer firm, for whom he installed power plant at Niederloesnitz. Having, in 1897, installed power plant in the Braunschweig Machinenbauanstalt, he remained with the firm for 5 years designing and selling machine tools.

It was in 1902 that he came to England in search of wider opportunities for his technical and business ability. Beginning as an agent, he came into touch with Mr. E. Trevor L. Williams, acted as liquidator of the Roc Steel Casting Co. of West Drayton and, in association with Mr. Williams, created on the same site the Power Plant Co. in which to develop the production of double helical gearing under the Wuest patent. He developed turbine gears for land and marine work, having been responsible in 1909 for cutting the gears for Sir Charles Parsons' S.S. "Vespasian," and subsequently for many warships and passenger steamers. It was his ingenious arrangement of double-reduction turbine gearing which facilitated the application during the War of turbine drive to small cargo vessels.

Shortly before the War he became a British subject and subsequently assumed the name of Wingfield, his original name being Wiesengrund. Under his direction the works of the Power Plant Co. concentrated during the War on Admiralty and Ministry of Munitions work, and he did not spare himself in his service to this country. When the conviction grew upon him that the severance of his connection with the works which he had built up might enable them to render still greater national service, he did not hesitate in 1918 to dispose entirely of his interest in them and withdrew completely. He then turned his energies to developing the Steam Fittings Co., of which Mr. Williams and he had retained control. Beginning with the improvement of steam-trap design, he gradually extended the range of products of the business and it became desirable to change the name of the company to the Drayton Regulator and Instrument Co. To the day of his death he was actively engaged in directing this business.

He was elected an Associate Member of the Institution in 1908 and a Member in 1911. A. P.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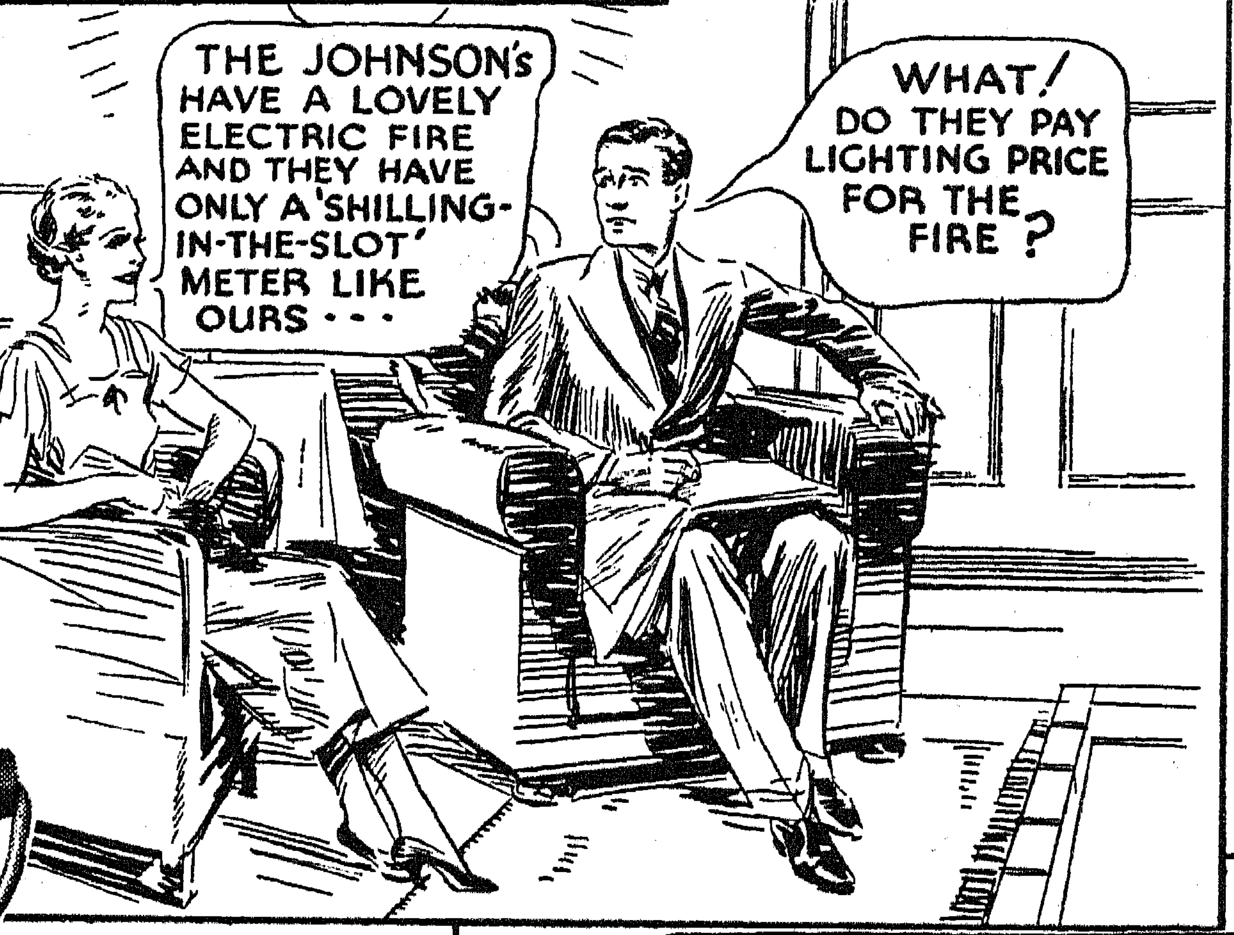
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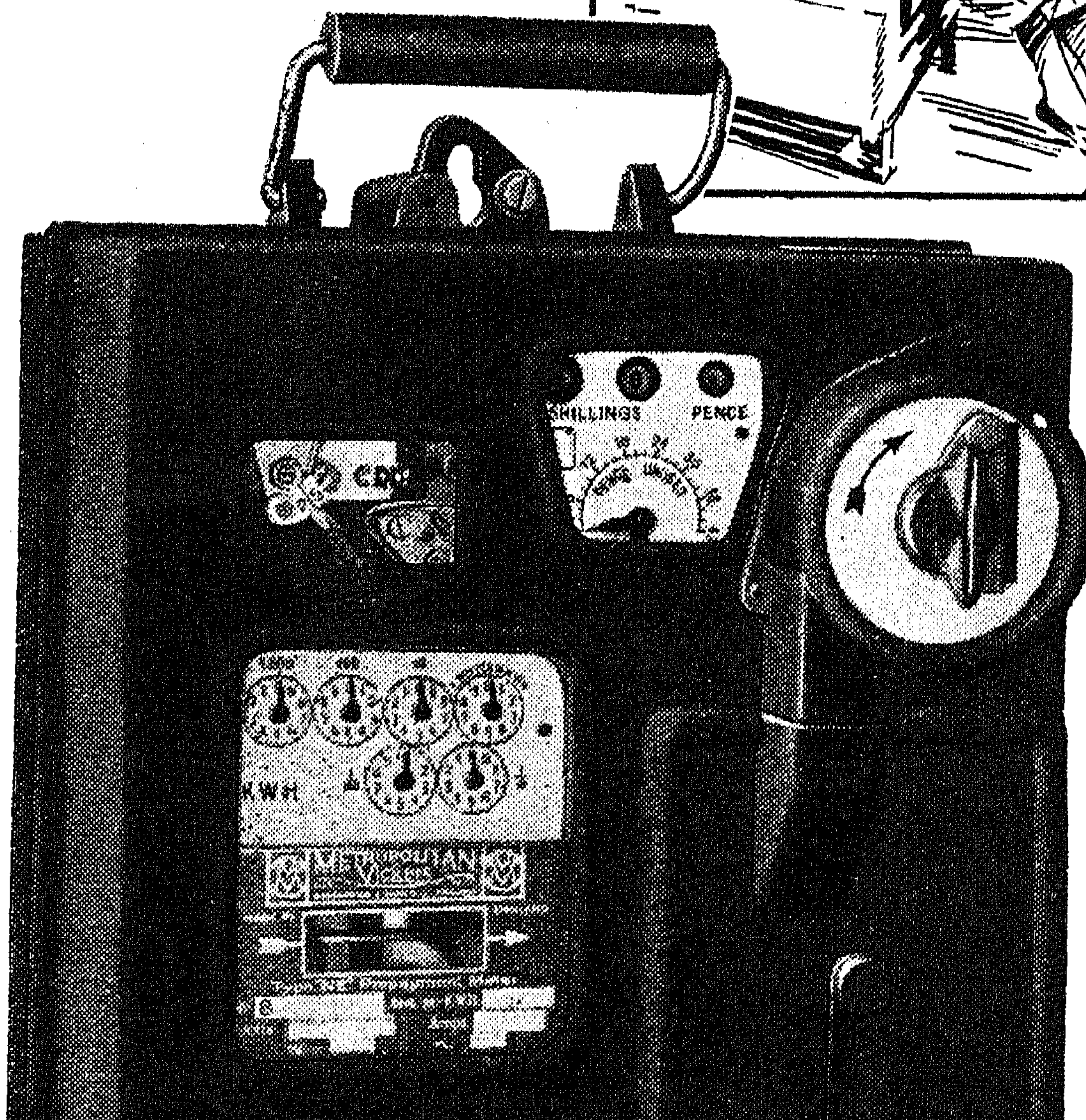

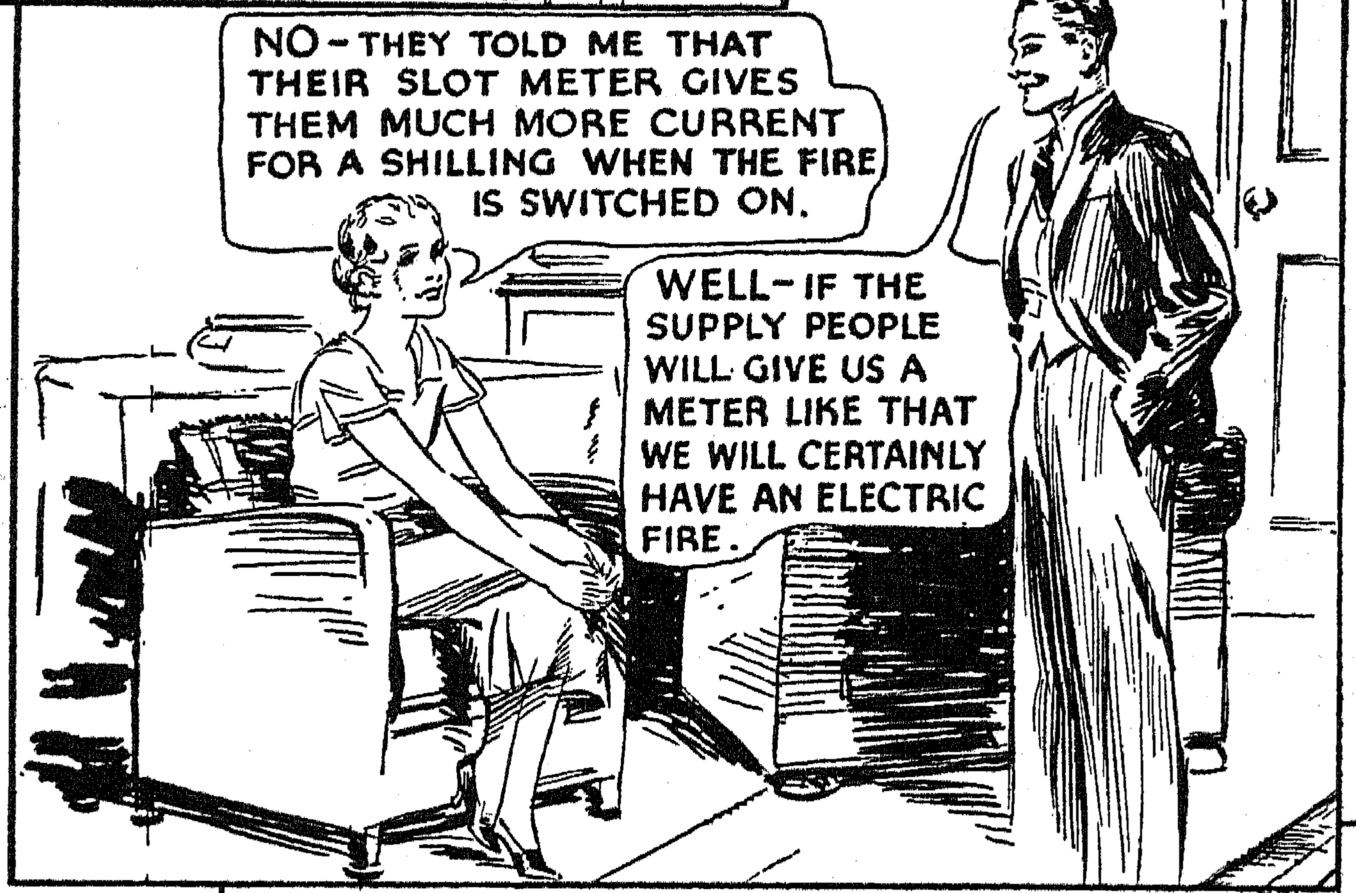
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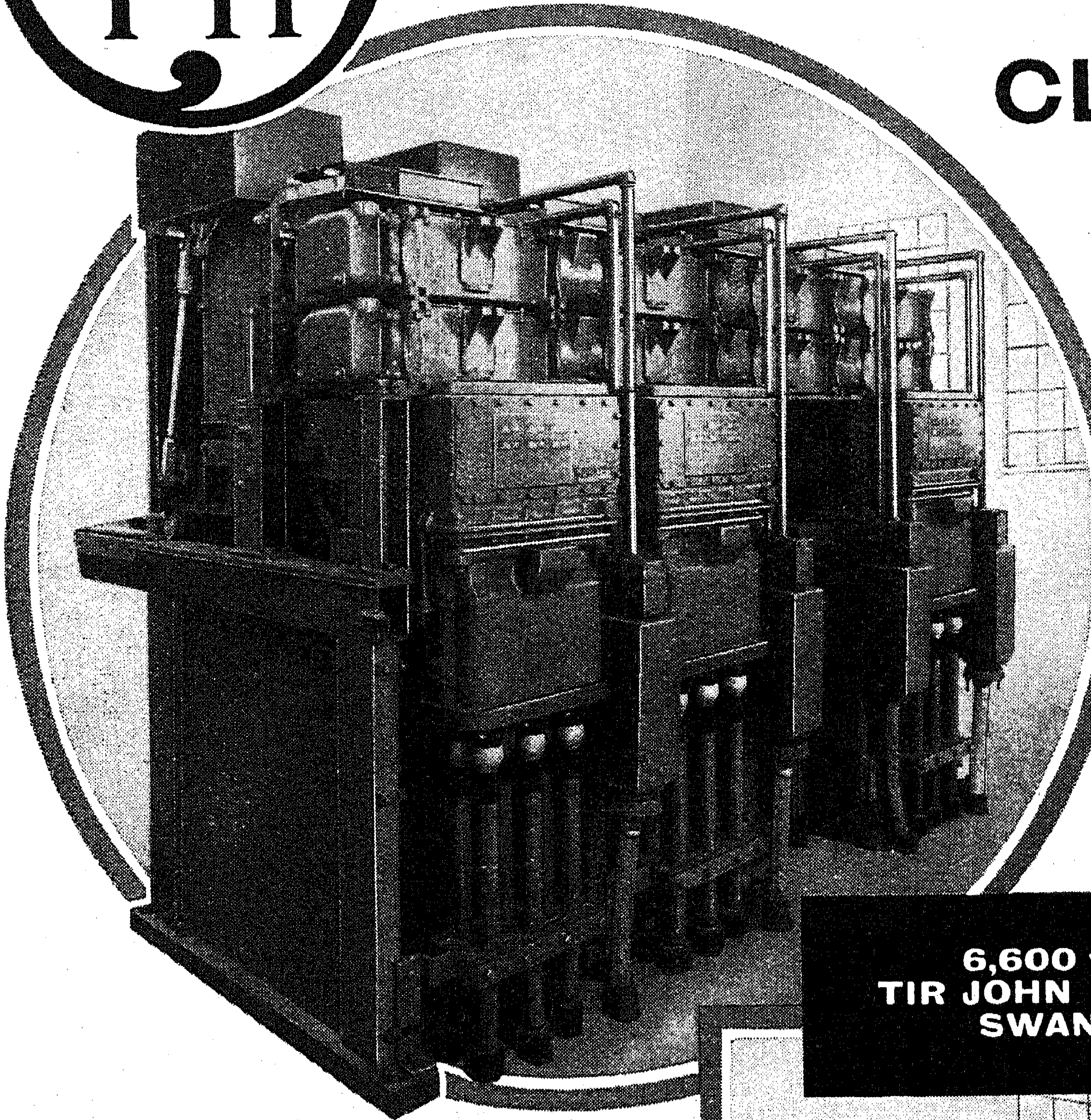

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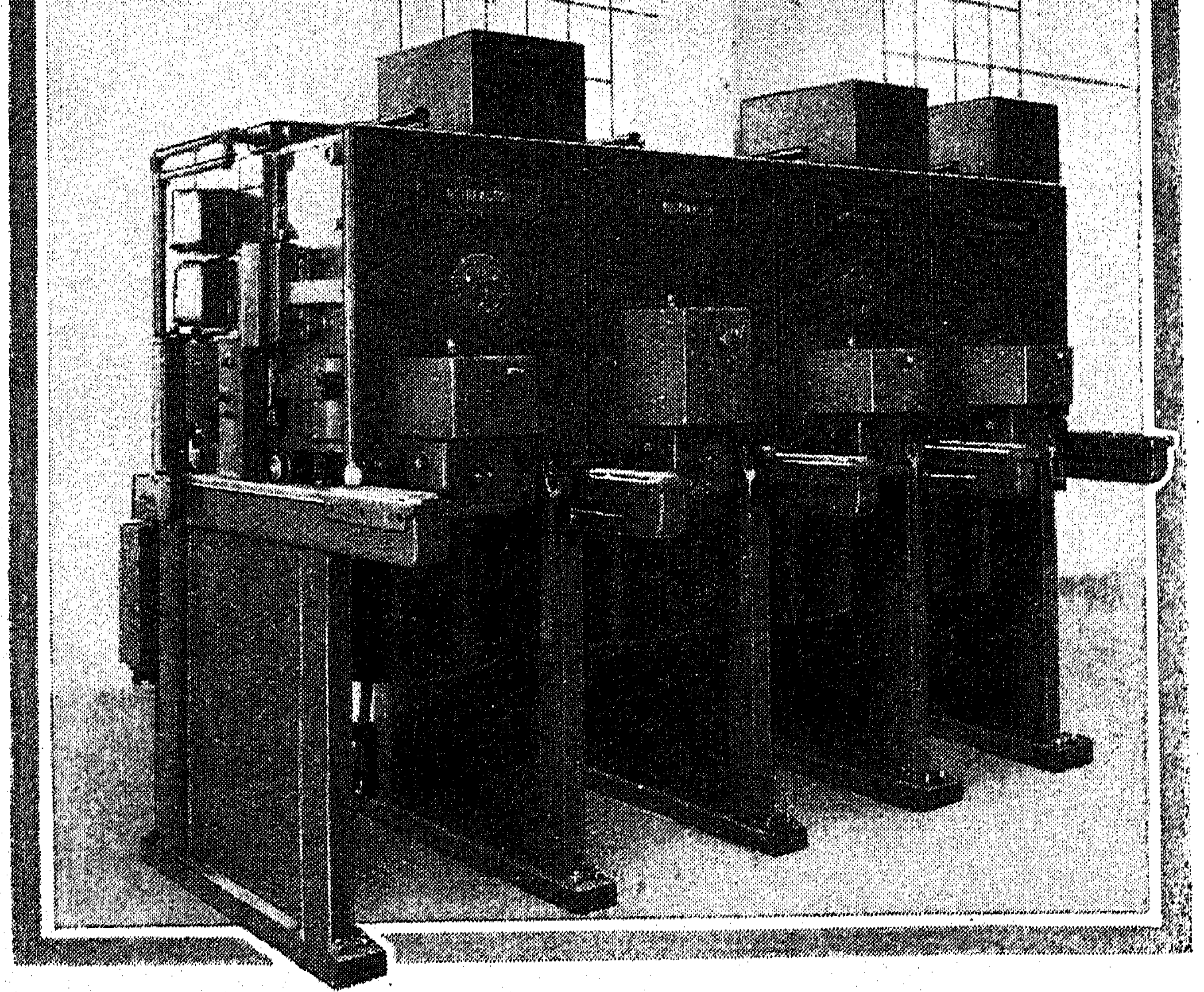

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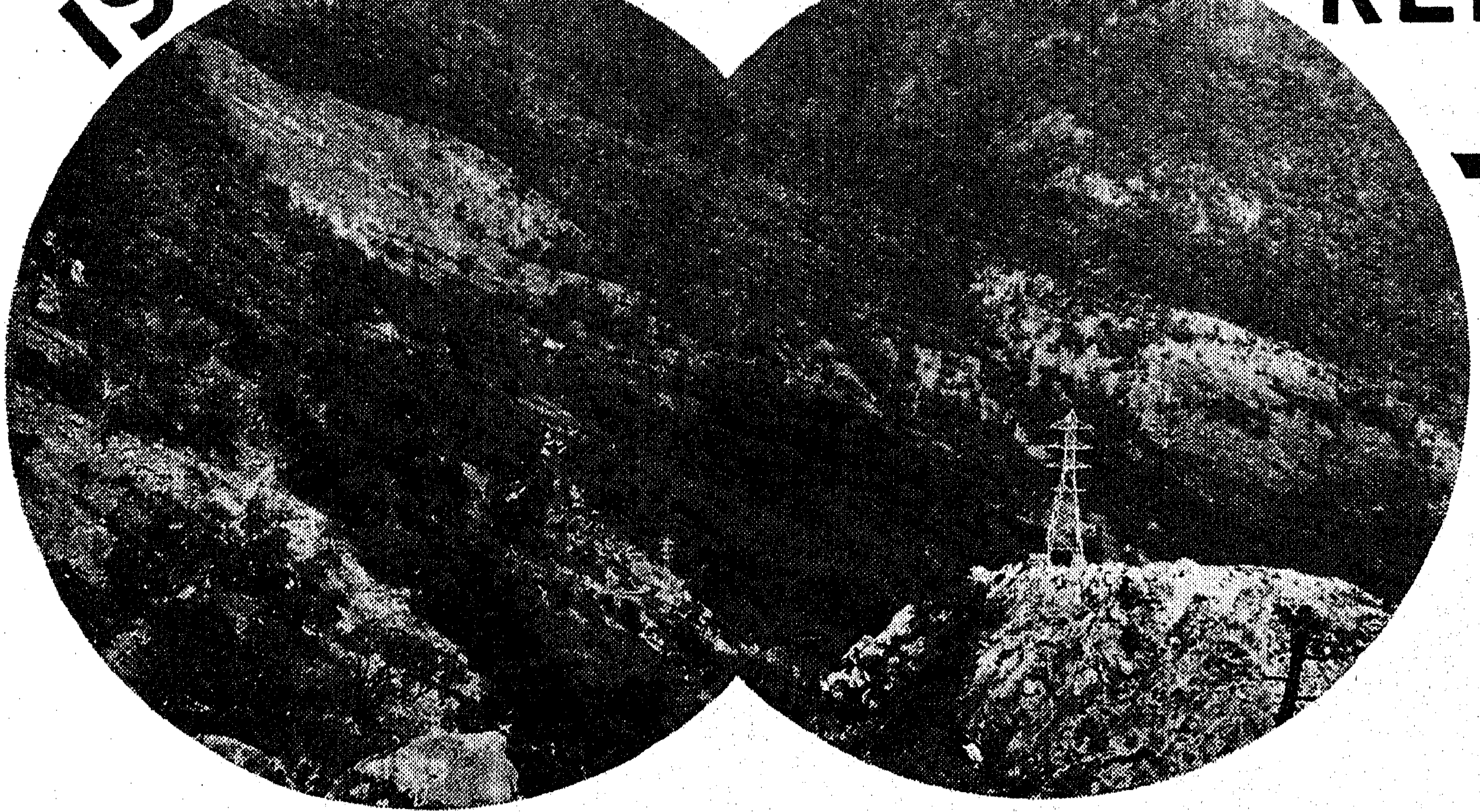

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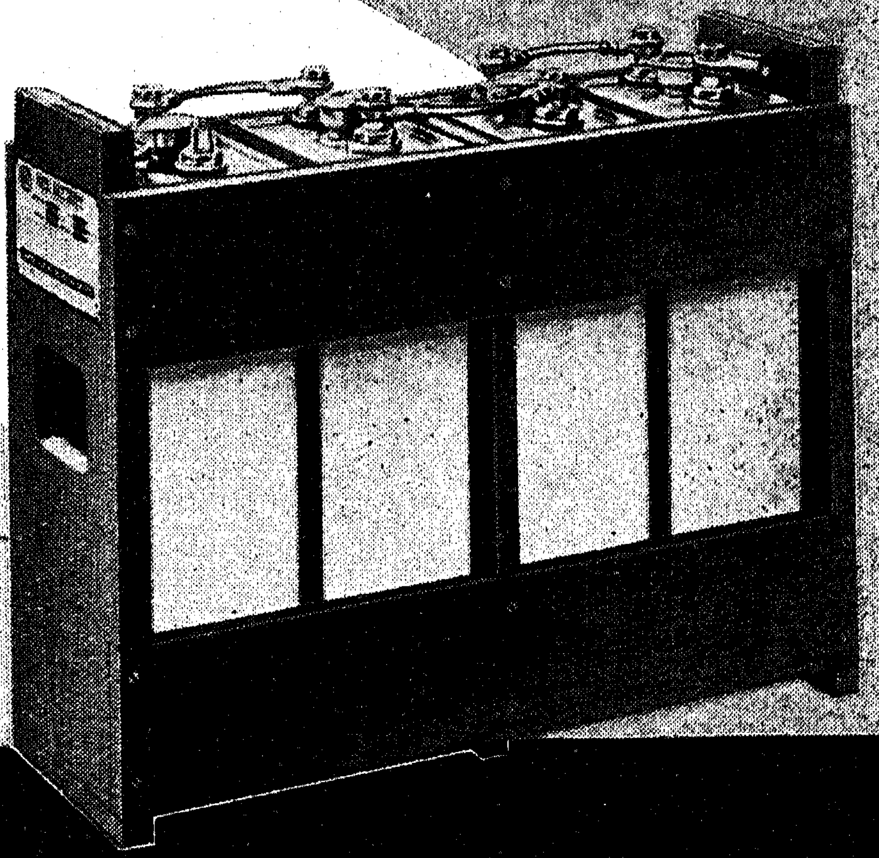

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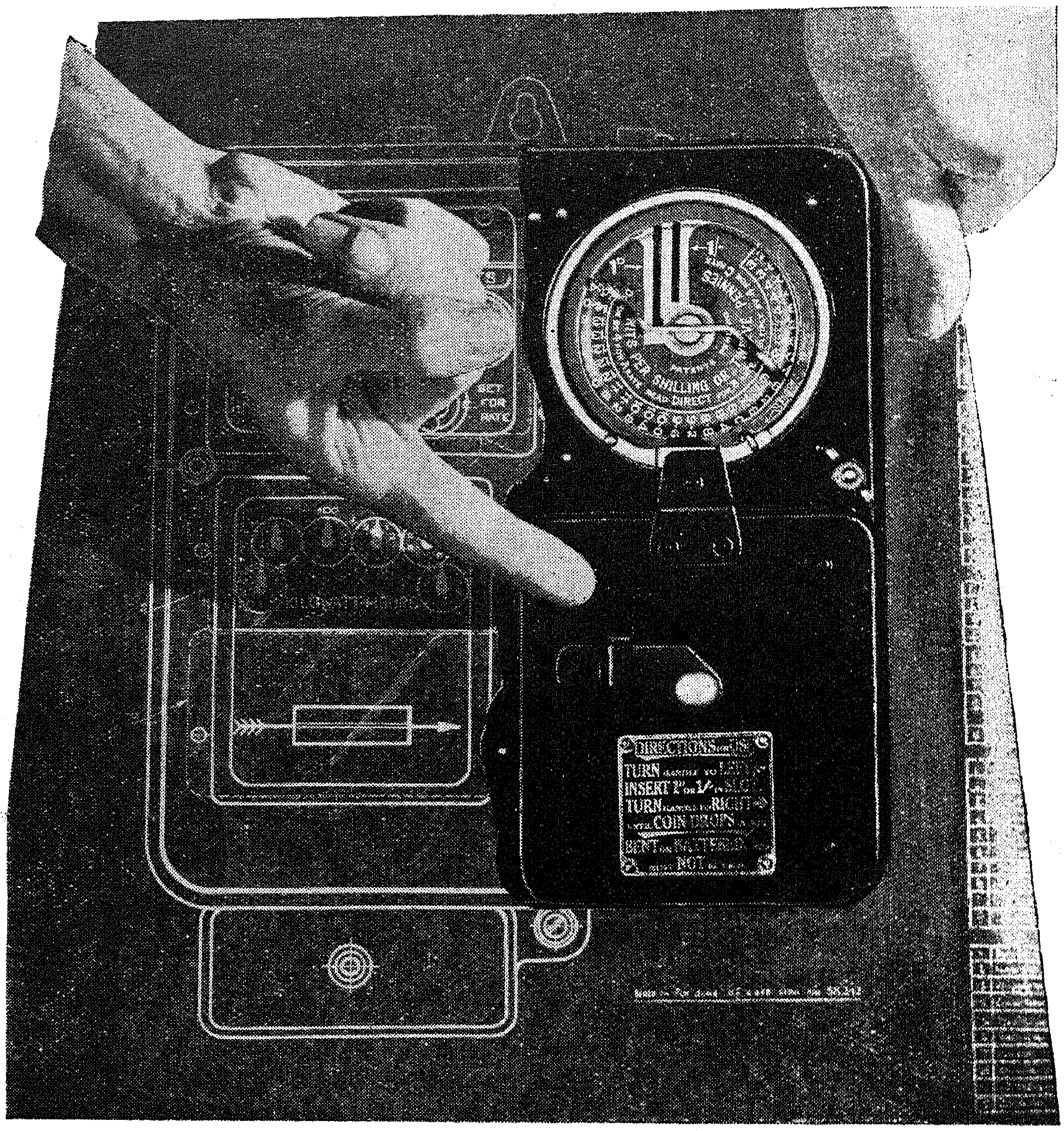

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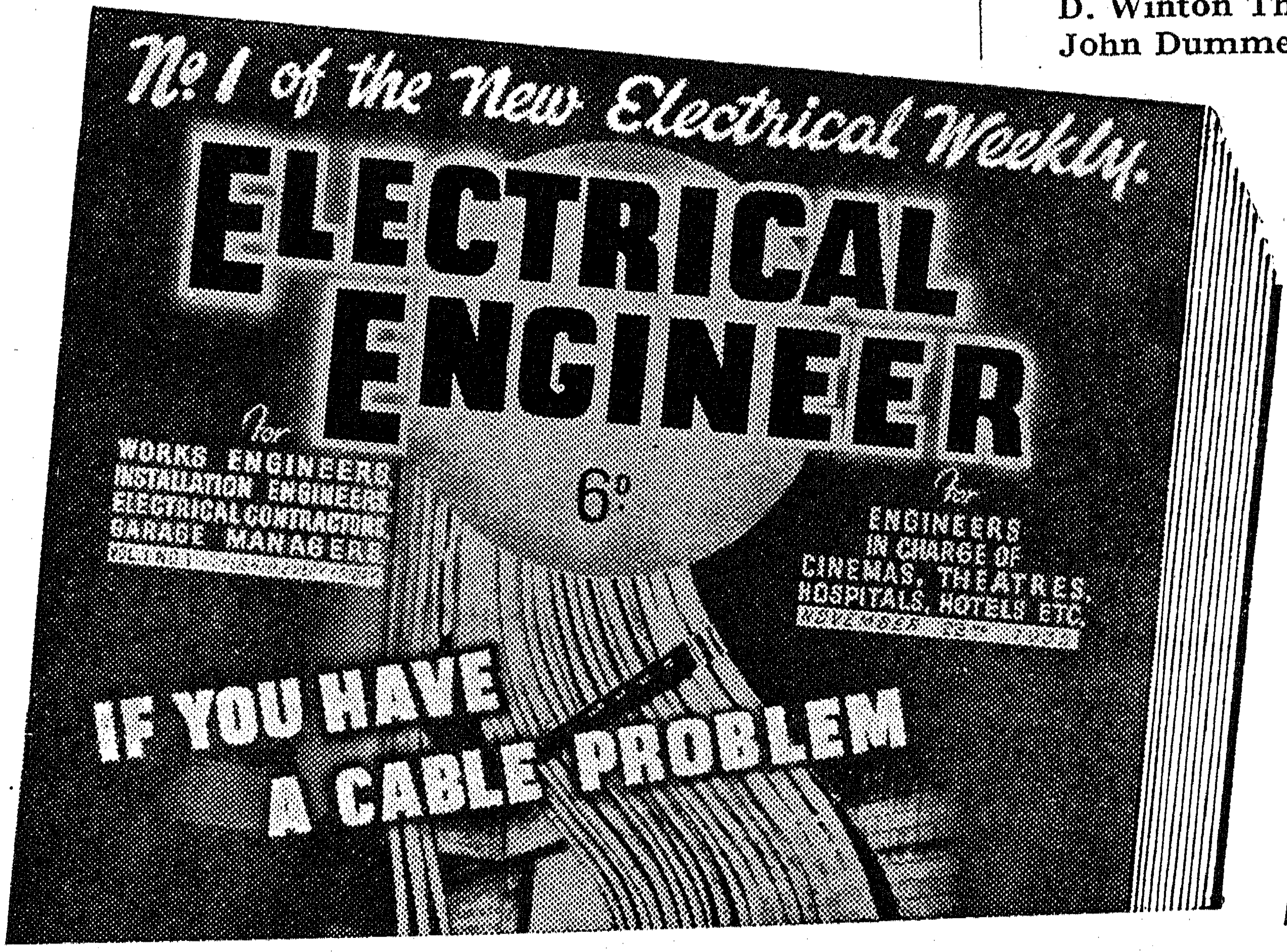

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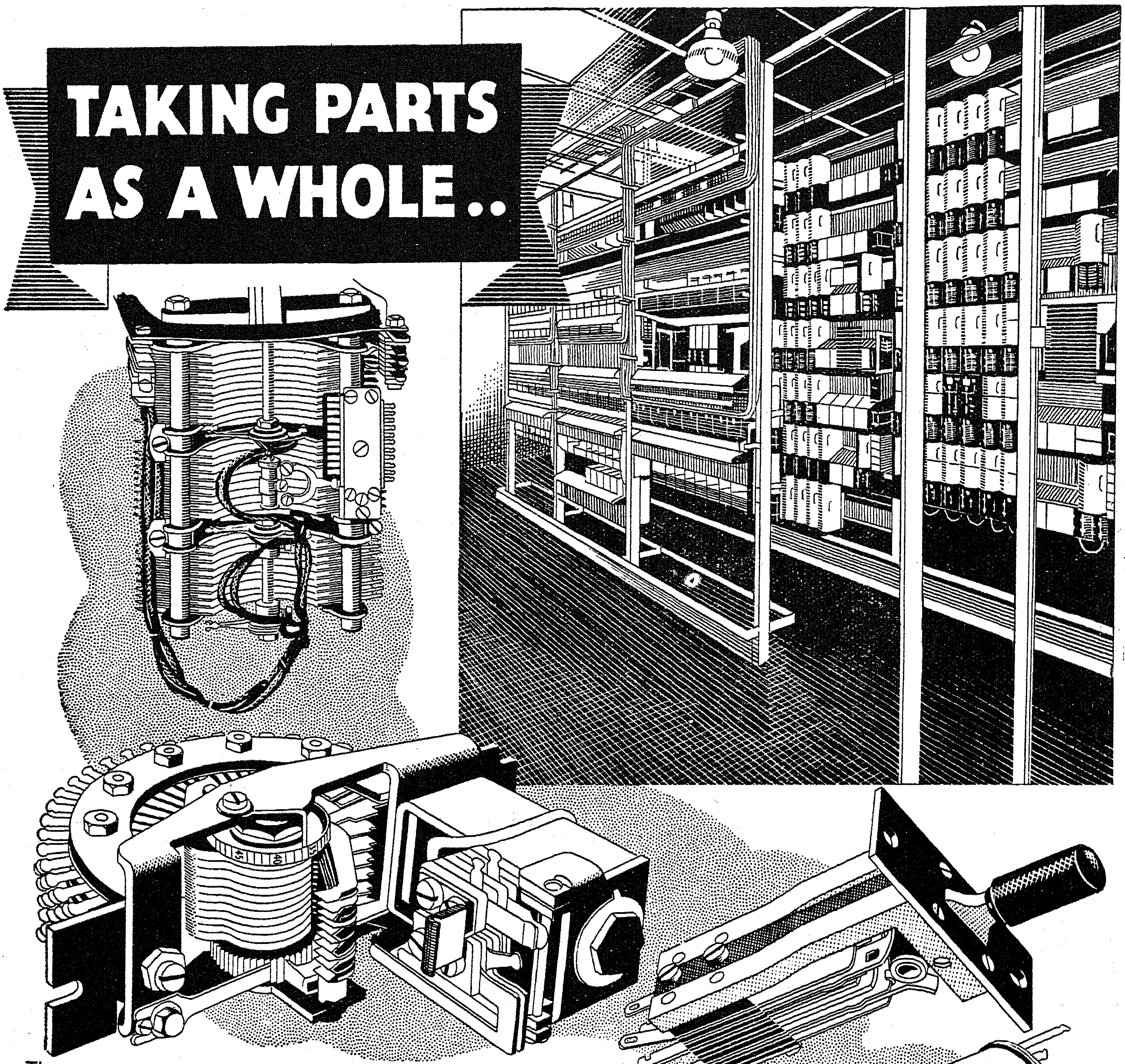

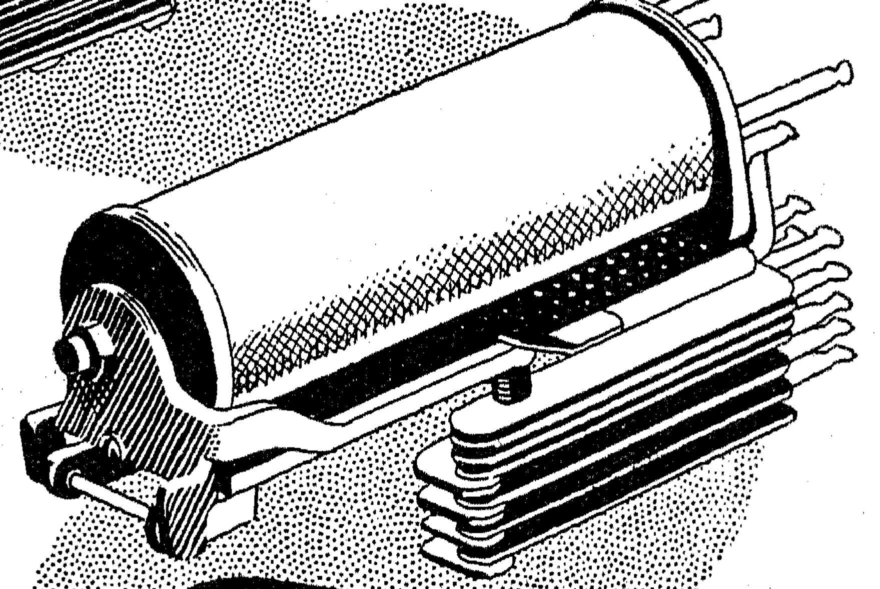

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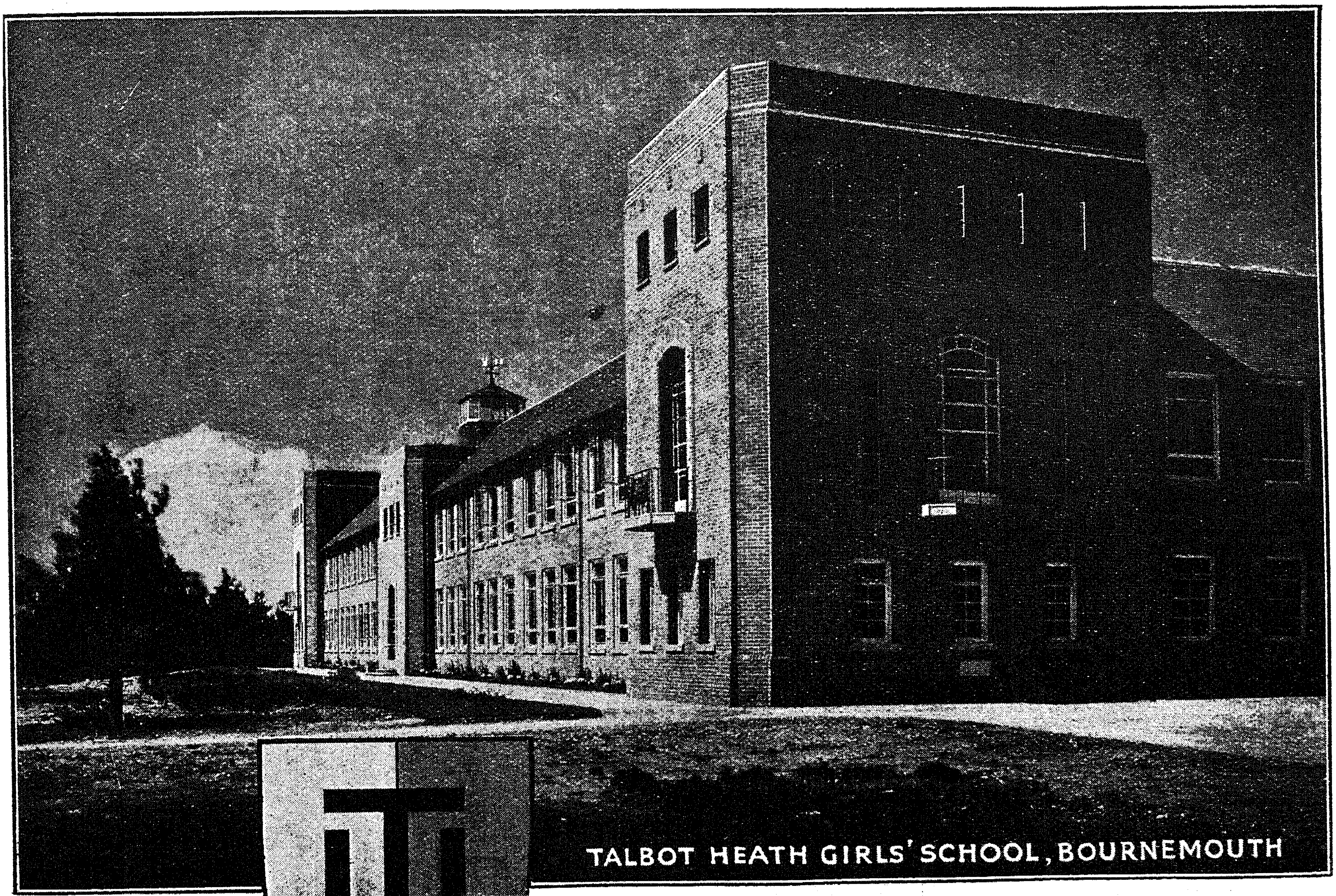

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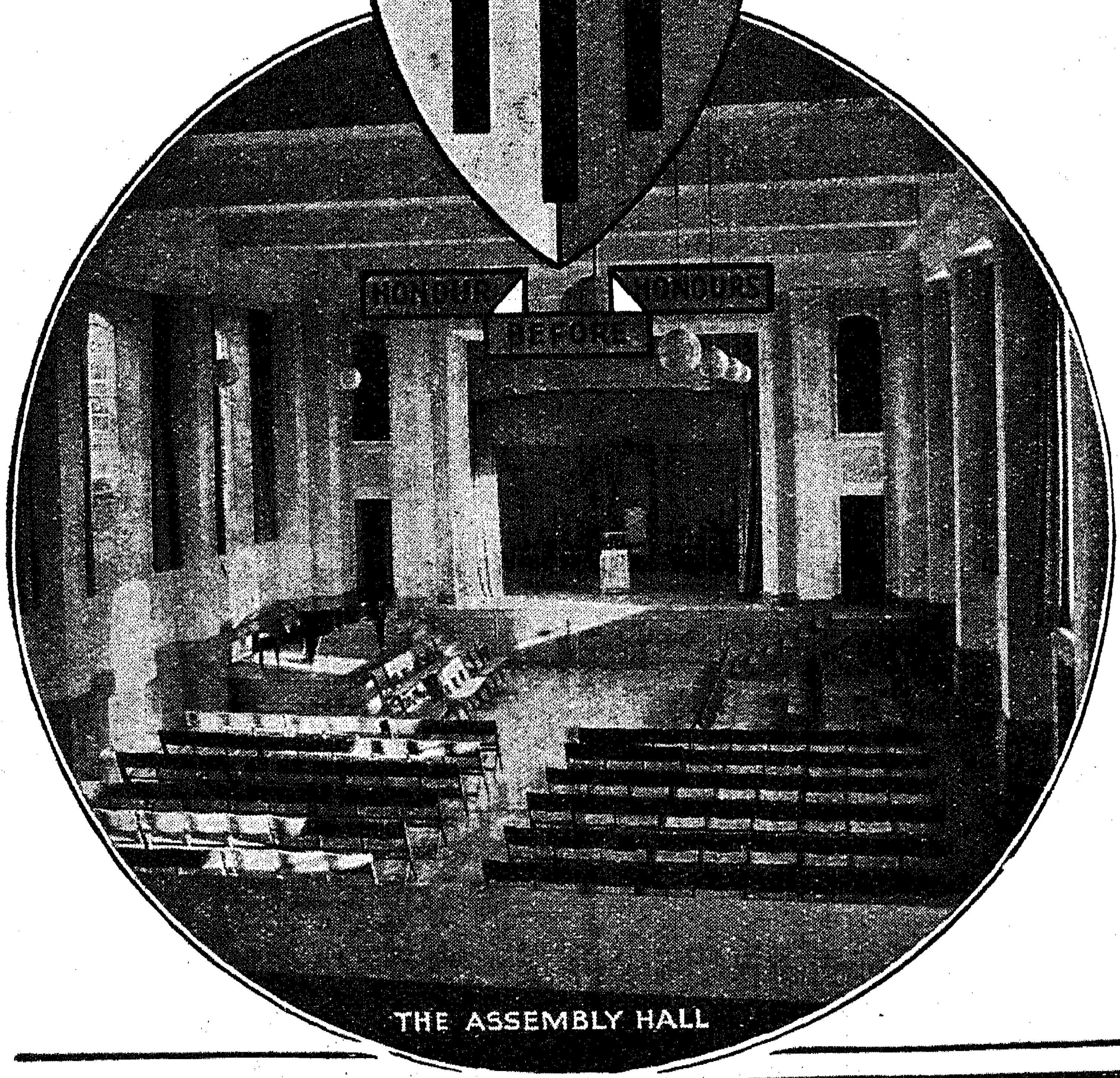

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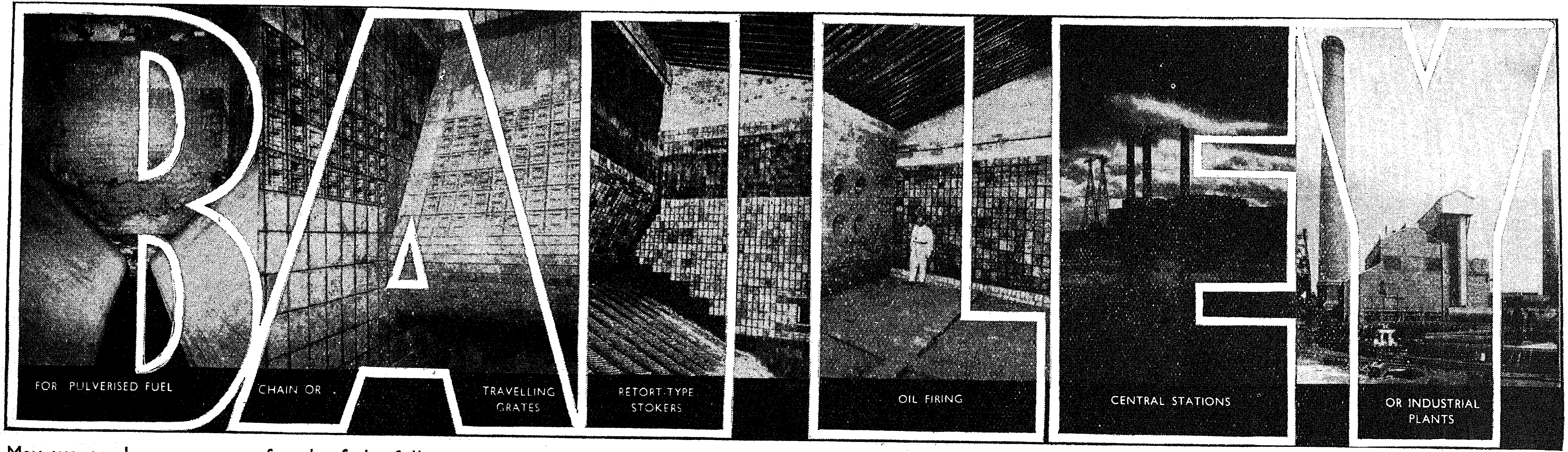

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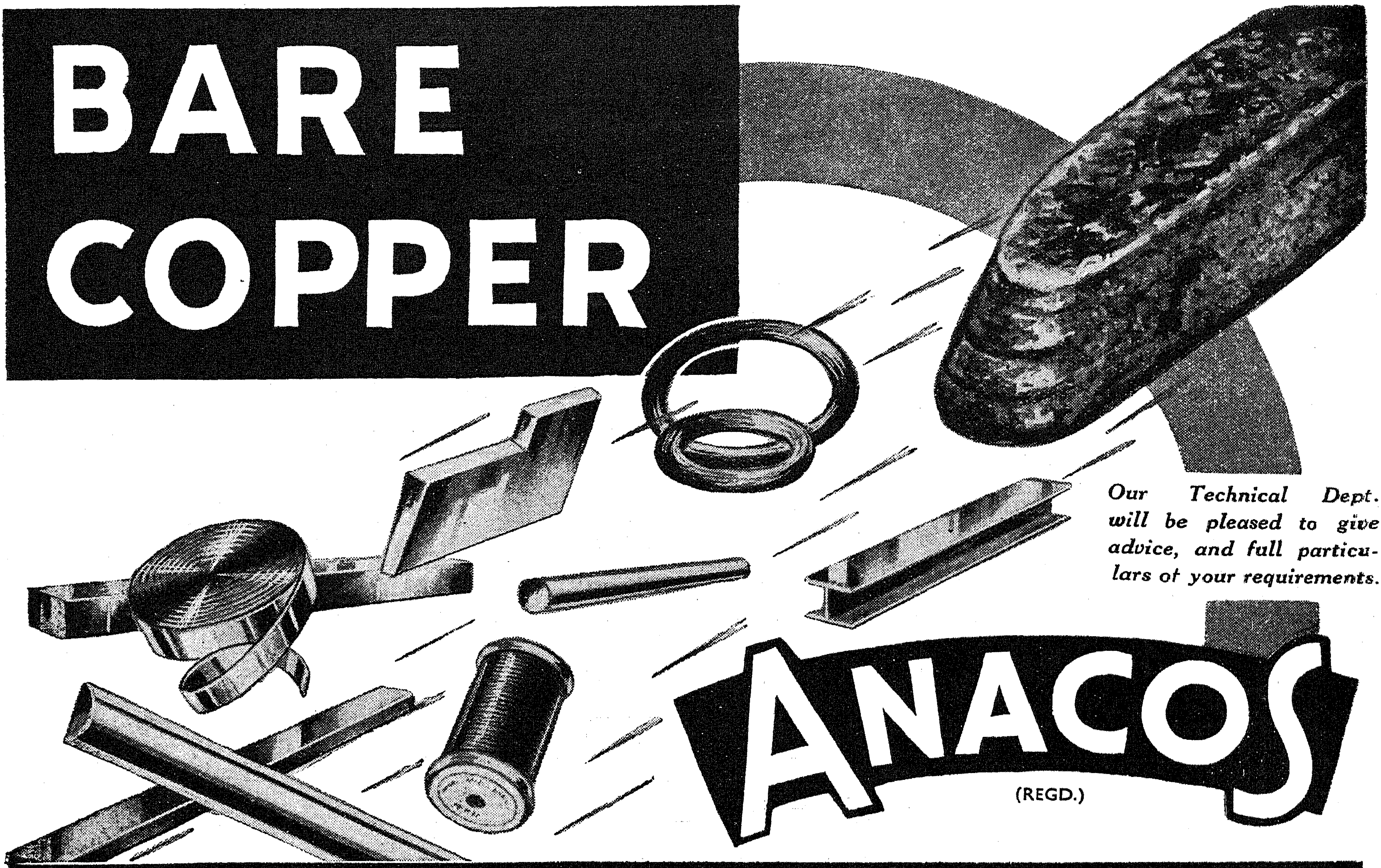
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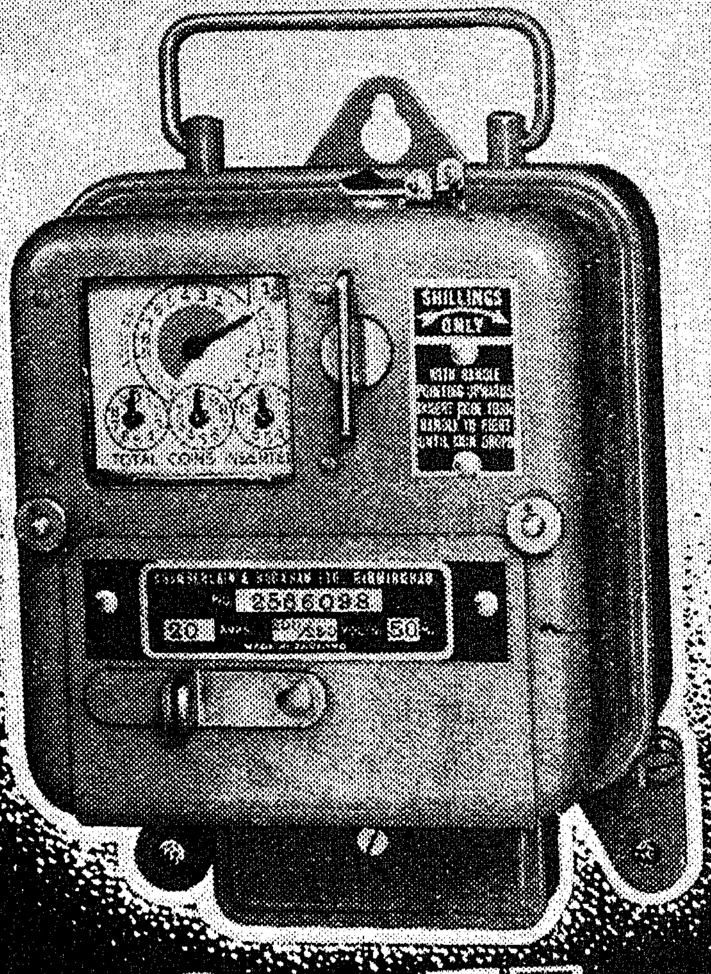

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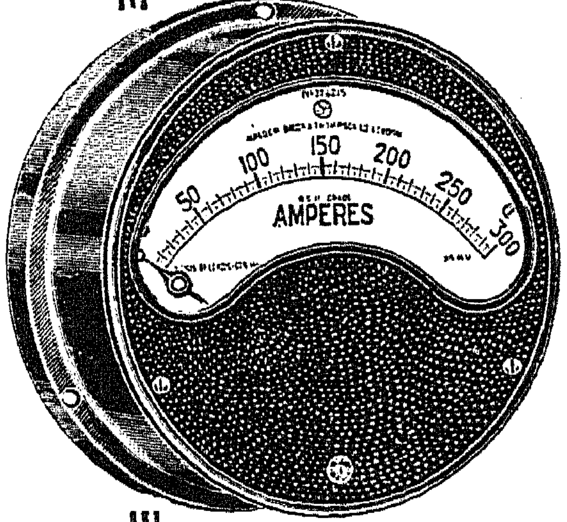

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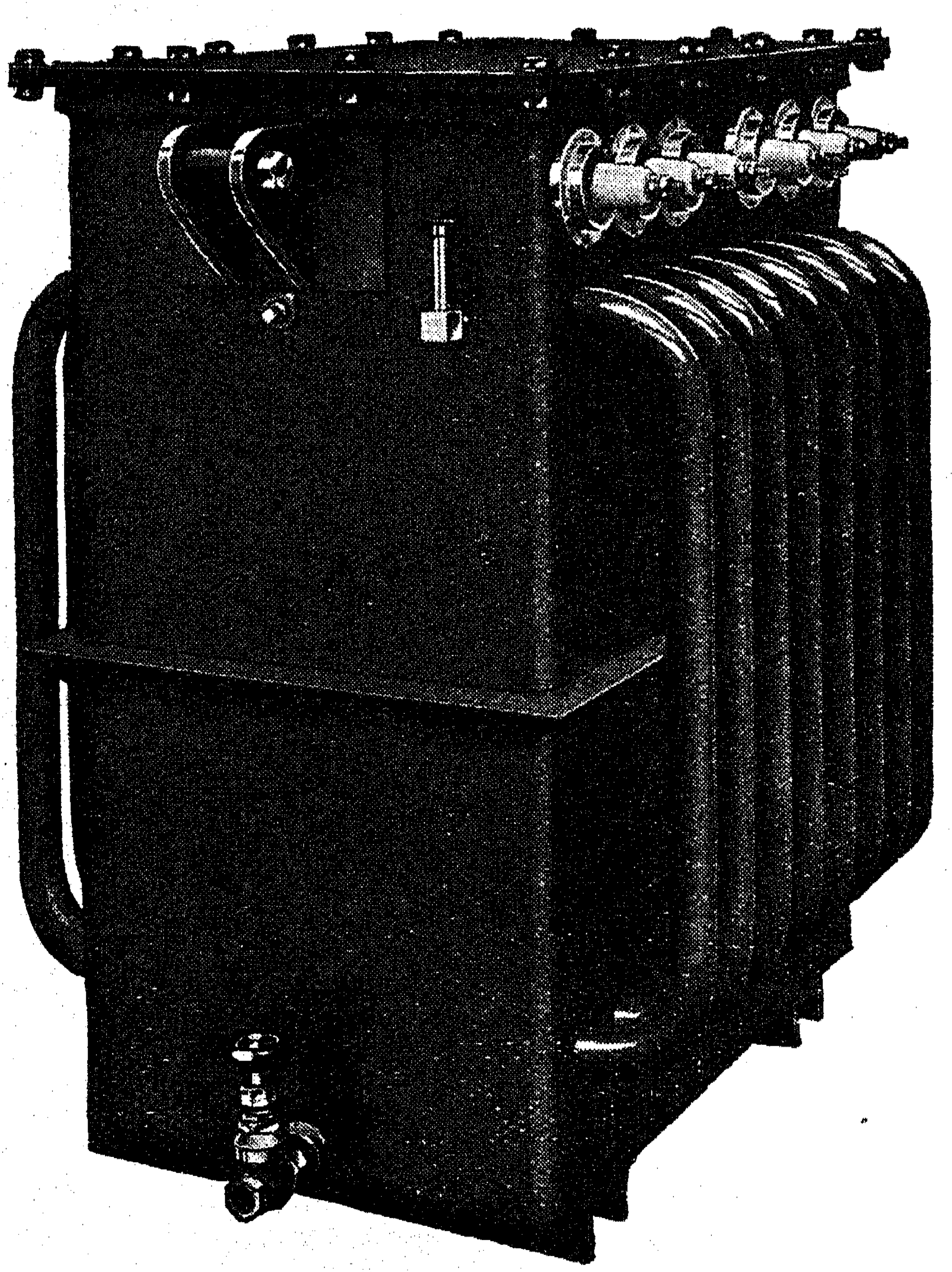

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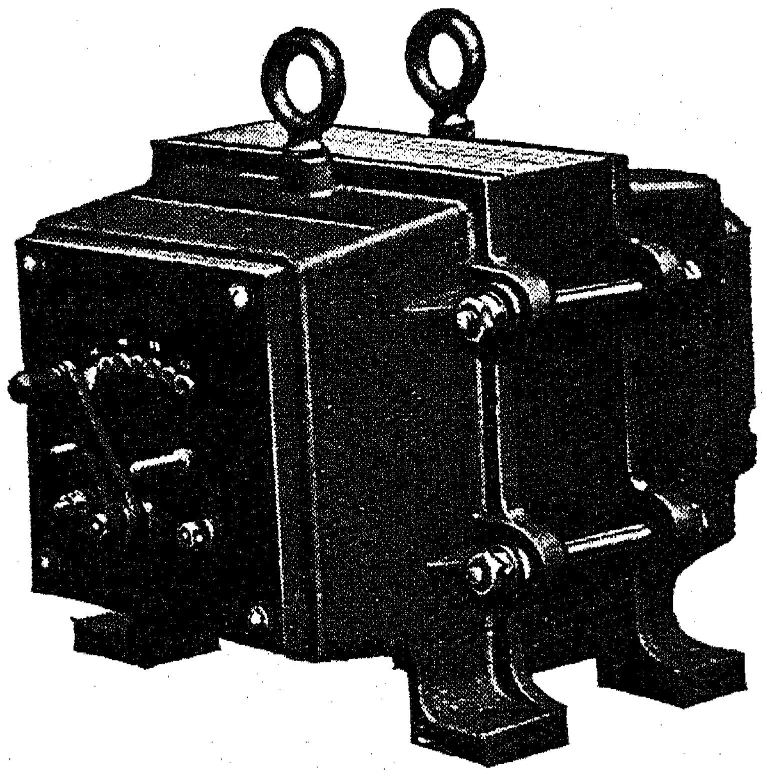

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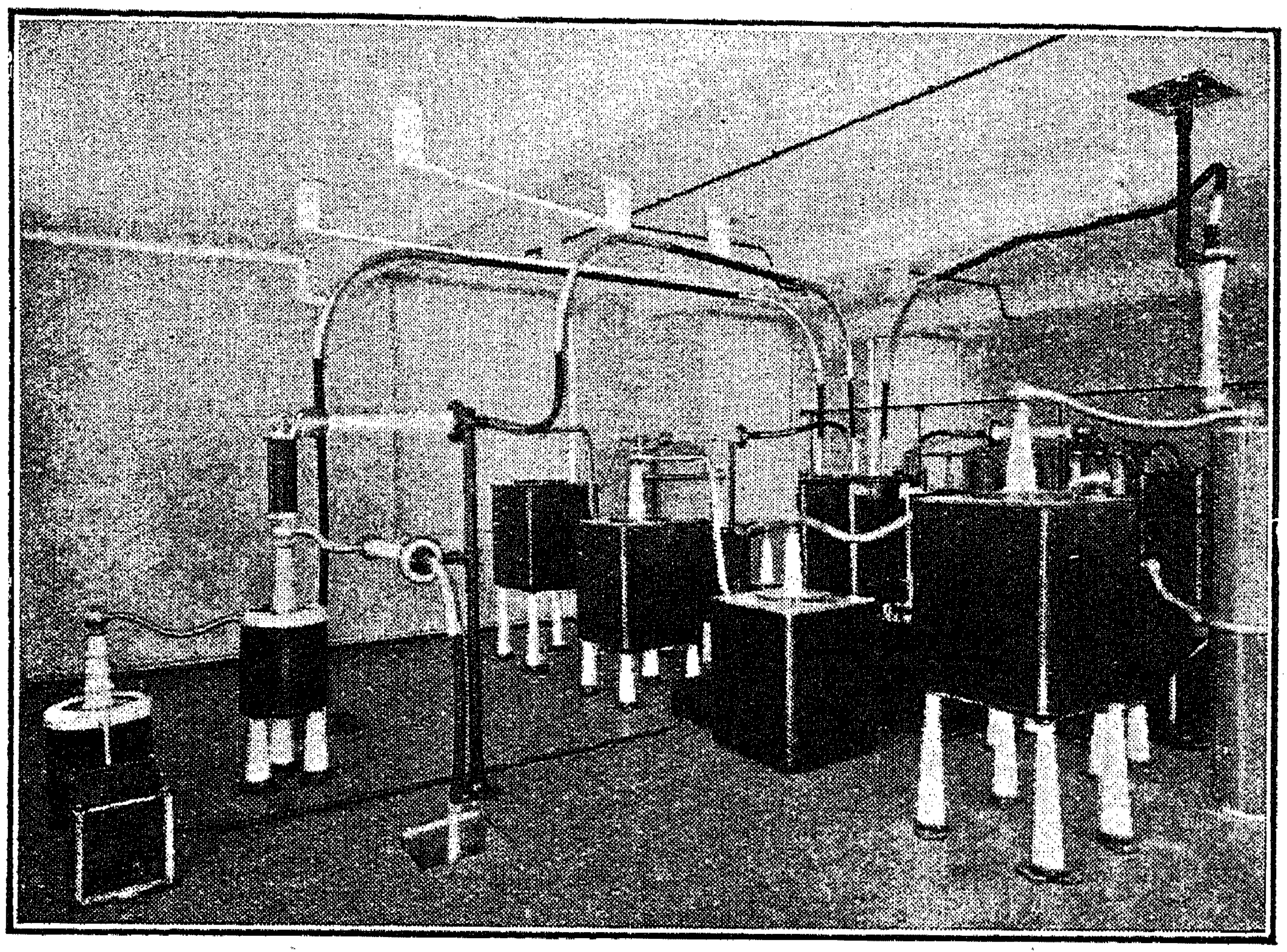

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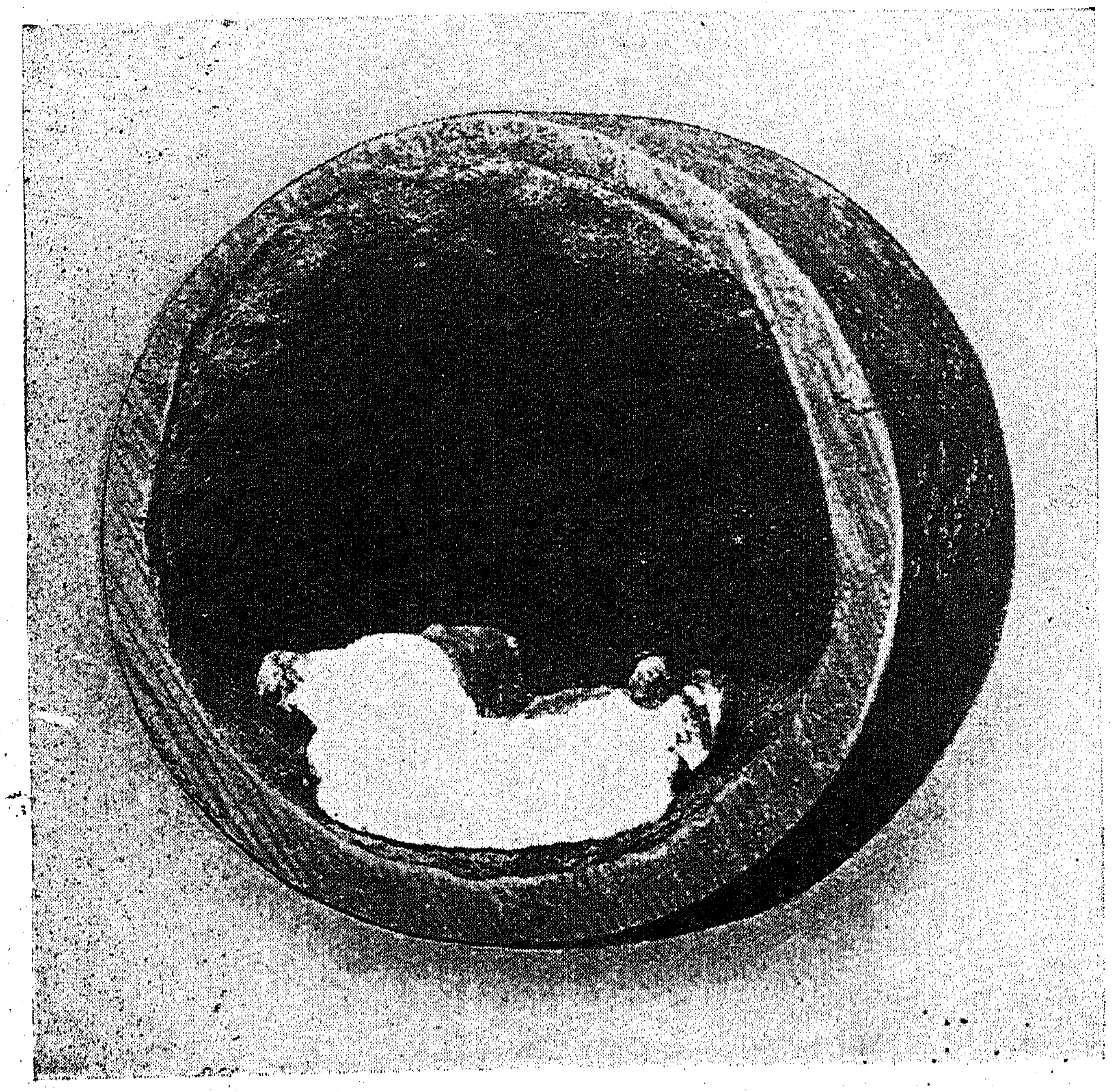

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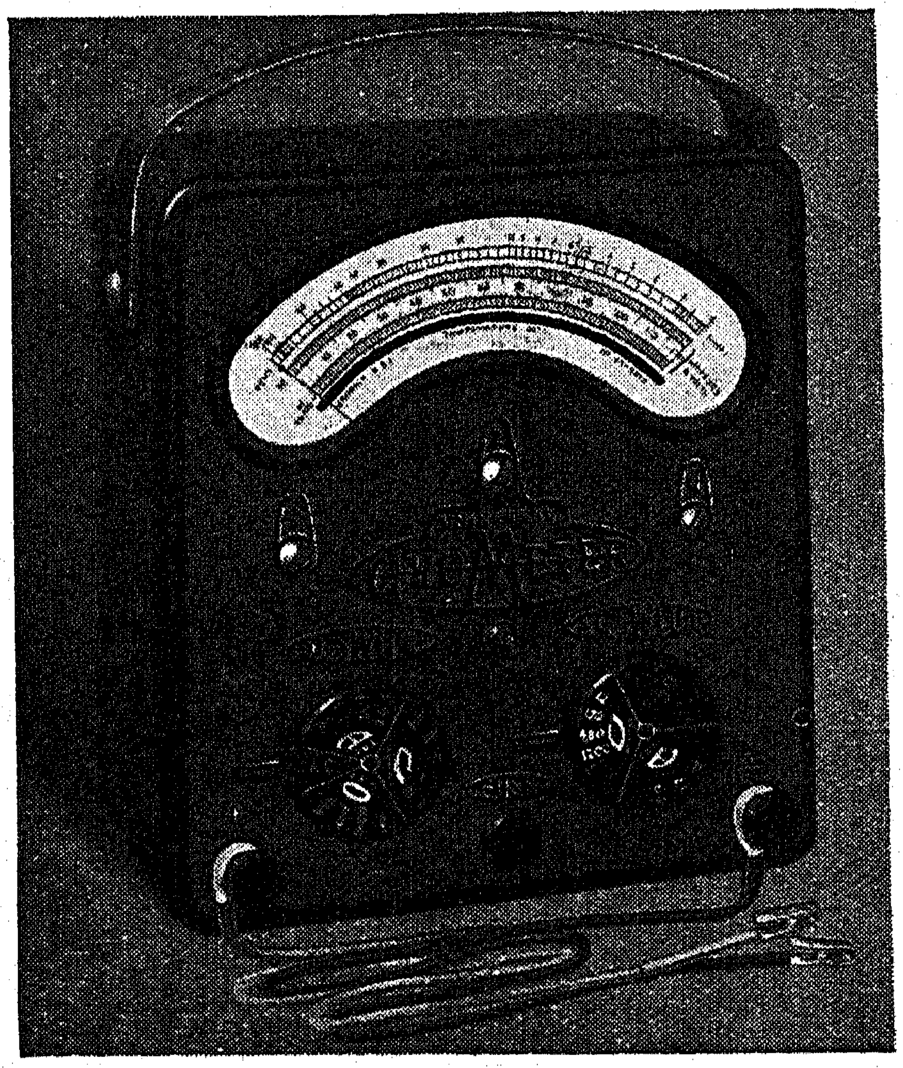

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